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OF

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Constitution, Article VII, Sec. 2.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XII JANUARY TO DECEMBER, 1895.

New York, January 16th, 1895.

The 93d meeting of the INSTITUTE was held this date at 12 West 31st street, and was called to order by President Houston at 8 P. M.

The Secretary read the minutes of the last meeting which on motion were approved, also a list of associate members elected and transferred at the last Council meeting, as follows:

Name.	Address.	Endorsed by.
ANDERSON, HENRY S.	General Manager and Electrician, United Electric Light Co., Springfield, Mass.	Geo. W. Blodgett. W. Stanley. W. L. Robb.
BUCK, H. W.	Student in Electrical Engineering, Columbia College; residence, 14 E. 45th St., N. Y. City.	F. B. Crocker. G. F. Sever. C. T. Rittenhouse.
COX, EDMUND V.	Student in Electrical Engineering Columbia College; residence, 50 E. 31st St., N. Y. City.	F. B. Crocker. G. F. Sever. C. T. Rittenhouse.
DENISON, SYLVESTER P.	143 Centre Street, New York City; residence, Belleville, New Jersey.	Jos. Wetzler. R. W. Pope. Geo. M. Phelps.
FARNSWORTH, ARTHUR J.	Chief Engineer, Larchmont Electric Co., Mamaroneck, New York.	Chas. R. Cross. W. L. Puffer. R. W. Pope.
FISHER, HENRY W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	Wm. Maver, Jr. Harris J. Ryan. Fred'k Bedell.
FRIDENBERG, HENRY LESLIE.	*M. E.*, Student in Electrical Engineering, Columbia College; residence, 60 E. 61st St., N. Y. City.	F. B. Crocker. G. F. Sever. C. T. Rittenhouse
GALLAHER, EDWARD B.	Electrical Engineer, 253 Broadway, room 910; residence, 1190 Madison Ave., N. Y. City.	L. W. Serrell. Jos. Wetzler. T. C. Martin.
KLINCK, J. HENRY.	Graduate Student, Cornell University, Ithaca, N. Y.	Harris J. Ryan. Fred'k Bedell. Ernest Merritt.

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LANPHEAR, BURTON S.	Fellow and Graduate Student in Electrical Engineering, Cornell University; residence 106 Union Ave., Ithaca, N. Y.	Fred'k Bedell. Ernest Merritt. Harris J. Ryan.
LESLIE, EDWARD A.	Vice-President and Manager, Manhattan Electric Light Co., L't'd, N. Y. City; residence, 343 Hancock St., Brooklyn, N. Y.	Edw. Caldwell. Ralph W. Pope. Wm. Maver, Jr.
LESTER, WILLIAM B.	Western Union Tel. Co., 195 Broadway; residence, 346 Lenox Ave., New York City.	G. W. Gardanier. James Hamblet. Richard Pfund.
RENNARD, JOHN CLIFFORD, *A. B. E. E.*,	Assistant to Electrical Engineer, Met. Telephone and Tel. Co.; residence 302 W. 73d St., New York City.	John J. Carty. M. I. Pupin. F. B. Crocker.

Total, 13.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, October 5, 1894.

WRIGHT, PETER	Inspector of Electrical Works, United Gas Improvement Co., Philadelphia, Pa.
ABBOTT, ARTHUR V.	Chief Engineer, Chicago Telephone Co., Chicago. Ill.

Approved by Board of Examiners, December 17, 1894.

MARKS, LOUIS B.	Electrician, Marks-Ayer Electric Co., 73 Watts St., New York City.
BAILLARD, EDWARD V.	Manufacturer of Electrical Instruments, etc., 108 Liberty St., New York City.
BROADNAX, FRANCIS	Engineer, Safety Insulated Wire and Cable Co. New York City.

Total, 5.

Dr. A. Macfarlane then read the following paper "On the Units of Light and Radiation."

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A paper presented at the Ninty-third Meeting of the American Institute of Electrical Engineers, New York President Houston in the Chair. and Chicago, Mr. S. Arthur Rhodes in the Chair, January 16th, 1895.

ON THE UNITS OF LIGHT AND RADIATION.

BY A. MACFARLANE, D.SC., LL.D.

One of the recommendations made by the sub-committee of the INSTITUTE in the programme for the International Electrical Congress at Chicago, was that the practical unit of illumination should be defined as the illumination produced by the bougie-decimale at the distance of one metre, and that this unit should be denominated the "bougie-metre." To this definition little objection was made, excepting that Professor Nichols pointed out that it involved an arbitrary standard of light which had no relation to the C. G. S. system of units. More general objection was taken to the notation for the unit.

The London *Electrician* for February 3, 1893, objected to the "bougie-metre," that all other such compound names imply a product of the components, while in this case the former component is divided by the latter, or, more correctly, multiplied by the square of its reciprocal; and suggested, half seriously, that instead of "candle-foot" we ought on the "mho" principle to speak of "candle-toof-toof."

M. Hospitalier made the same objection, that "bougie-metre" according to existing usage means a product, and suggested "bougie-at-a-metre," or, if that were inadmissible the use of a new term such as "lux." M. Blondel favored the single term "lux," and Mr. Lockwood, the single term "davy."

Consider the philosophy of the substitute suggested by the *Electrician*. If we attempt to formulate the "mho" principle, we find that it may be expressed as follows:—The reciprocal of a given unit may be denoted by writing the name for the direct unit backwards. It supposes that the given unit can be expressed

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as the ratio of two other units; thus, ohm is the single name for the ratio, volt per ampere. The reciprocal idea is ampere per volt, and there is a convenience in not introducing a new and independent word, but in denoting it instead by the direct term written backwards.

It appears to the writer that here we have a principle which might well be adopted in mathematical analysis, for we have all felt the want of a suitable notation for a function, which is the reciprocal of a given function; for example, the reciprocal of *tan* or *sin*. English and American writers use tan^{-1} and sin^{-1}, a notation which is half word, half symbol; which cannot be pronounced; and which suggests the reciprocal quantity instead of the reciprocal function. Continental writers use "arc tan" and "arc sin," which are too long and periphrastic. On the "mho" principle, the reciprocal of "tan" is "nat" and that of "sin" is "nis." Let $x = \tan y$, then $y = \text{nat}\, x$; let $a = \sin b$, then $b = \text{nis}\, a$. According to Lord Kelvin, who, I believe, introduced the "mho" notation, the expression for a function should consist of three letters; and it may be added, the middle letter ought to be a vowel, the other two consonants. Such a syllable notation when inverted remains a syllable. This notation would have the advantages of being short, unambiguous, articulate and logically connected.

But in the case of a fundamental unit, such as the foot, is there any reciprocal idea? It is true that there are physical quantities which have the dimension l^{-1}; but on examination they will be found to express a physical ratio of some kind. For example the unit of curvature has the dimension l^{-1}; it is expressed by radian per foot. The reciprocal unit is foot per radian, having the dimension l; it is not a measure of length, but of flatness.

The difficulty experienced in expressing the intensity of a candle or other spherical source arises from the want of a name for the unit of solid angle. Just as the natural unit for plane angle is metre of arc per metre of radius, so the natural unit for solid angle is square metre of spherical surface per metre of radius squared. The name "radian" given to the former unit (Everett's "Units and Physical Constants," 1879), has been very useful in expressing exact ideas; a recognized name for the latter unit would also be highly useful. For this purpose the word "steradian" was introduced by Dr. Halsted in his Metrical Geometry in 1880, and I have used it in my work on Physical Arithmetic. Though

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not faultless from the point of view of the etymologist, it is sufficiently expressive to the physicist.

How then is the unit of illumination properly expressed? Suppose that by "bougie" is meant the current of light which streams from a uniform standard candle through one "steradian," then the illumination anywhere may be expressed in terms of bougie per square metre, where the former component refers to the current, and the latter to the cross-section. But in the case of light streaming from a uniform point source, the illumination may be expressed in terms of (bougie per steradian) - (steradian per square metre), where the former component refers to the intensity of the source, and the latter to the solid angle subtended at the source by one square metre of cross-section. If "lux" is the single term for this unit, we have

lux = bougie per square metre
=(bougie per steradian) - (steradian per square metre).

Hence, candle per square foot or (candle per steradian) - (steradian per square foot) is the proper expression for the candle-toof-toof of the *Electrician*.

According to the above definition of "bougie," the total current from the candle would be 4π "bougies." But if "bougie" is defined to mean the total current from the candle, and by "lux" is meant the same quantity as before, we should have

$$\text{lux} = \frac{1}{4\pi} \text{ bougie per square metre.}$$

We cannot logically avoid the 4π; exclude it from the source it appears in the intensity, and *vice-versa*. This point is overlooked in the established system of magnetic units, and forms the basis of Heaviside's rational system.

The use of the hyphen to denote a product unit is not very appropriate, for it suggests the sign minus rather than the sign of a product. It would be better if it were omitted altogether, and the two component units amalgamated as in footpound and kilogrammetre; for then the nomenclature would correspond to the algebraic convention which leaves the sign $\times$ to be understood, and in addition the hyphen would be set free to denote any compound unit other than the product or quotient.

If we consider the general subject of radiation we shall be led to distinguish the following ideas with their corresponding units:

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TABLE I.

Idea.	C. G. S. Unit.
1. Quantity of radiant energy	Erg.
2. Current	Erg per sec.
3. Strength of source	Erg per sec.
4. Intensity of spherical source	Erg per sec. per steradian.
5. Intensity of cylindrical source	Erg per sec. per (cm.-radian).
6. Intensity of plane source	Erg per sec. per cm^2.
7. Density of source	Erg per sec. per cm^3.
8. Intensity of current	Erg per sec. per cm^2.
9. Time flow	Erg per cm^2.

Quantity of radiant energy of whatever kind can be expressed in ergs, and a *flow* in ergs per second. By *strength of source* is meant the whole quantity of radiant energy which leaves the source in a given time divided by the time; the appropriate unit is erg per second. The *intensity of a source* is differently expressed, according as the radiation is spherical, cylindrical, or plane. In the first case it is the ratio of a current through a solid angle to the solid angle, and hence it is appropriately measured by the erg per second per steradian. In the second case it is the ratio of a current through a wedge-angle to the wedge-angle. There is no recognized unit of wedge-angle; as it involves the radian in one plane, and a length along the perpendicular to that plane; it may be expressed by cm.-radian. Hence the intensity will be expressed in erg per second per (cm.-radian). If the radiation proceed from an infinite plane, its intensity is measured in terms of erg per second per cm^2.

By the *density* of the radiation at any point of a source, is

TABLE II.

Idea.		Unit.	Symbol.
French.	English.		
1. Quantité de lumière.	Quantity of light	Rad.; lumen-hour.	Q
2. Flux lumineux	Luminous flux	Lumen	F
4. Intensité lumineuse.	Luminous intensity	Pyr	I
7. Radiation intrinsèque	Intrinsic radiation	Lumen per cm^2	R
8. Éclairement	Illumination	Lux	E
9. Illumination	Quantity of illumination	Phot	L
Éclat intrinseque	Intrinsic brightness	Pyr per cm^2	E

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meant the ratio of the flow normal to a small surface, to the small surface, and is expressed in terms of erg per second per cm^2. By *intensity of current* anywhere, is meant the ratio of the flow through a small cross-section, to the cross-section, and it is also expressed in terms of erg per second per cm^2. By *time flow* is meant the ratio of the energy which has passed through a cross-section, to the cross-section; it is expressed in terms of erg per cm^2.

The above is the appropriate system of C. G. S. units for any kind of radiation measured simply as energy. But in the case of light, the eye exercises a selective power, not only singling out a certain range of wave-lengths, but discriminating among them as to amount. If one of the units is defined with reference to this discrimination exercised by the eye, then the other units of the light system can be defined in terms of it, and the units of length and time.

Recently M. Blondel has published (*La Lumière Électrique*, July 7, 1894), an ingenious and logical system of units of light with corresponding practical units. When the ideas are arranged in the same order as in Table I, we obtain the system exhibited in Table II.

By "pyr" is meant a luminous intensity equal to one-twentieth part of the luminous intensity of the Violle standard. By "lumen" is meant the current of light through a steradian, the spherical source having a uniform intensity of one pyr; that is,

$$\text{lumen} = \text{pyr-steradian}.$$

By "lux" is meant the illumination produced by a current of one lumen falling perpendicularly on a surface of one square-metre; hence,

$$\text{lux} = \text{lumen per square metre}.$$

The idea of No. 9 is expressed in French by illumination, but this word in English means éclairement; hence it has been proposed by M. Hospitalier to introduce "lumination" into both the French and the English languages to express the idea in question.

The "phot" is defined as equivalent to "lux-second." By "rad" is meant the unit of quantity of light. It is defined by

$$\text{rad} = \text{lumen-second}$$

just as the coulomb is defined by

$$\text{coulomb} = \text{ampere-second}.$$

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The "phot" and the "rad" are said to be of special use in photography. But it may be asked whether the actinic system of units is not independent of the optical system. Is not the "pyr" then defined by the actinic effect instead of the optical effect? If so, we have two complete systems of units, both different from, but parallel to the radiant energy system.

M. Blondel does not introduce Nos. 3 and 5. Let "bougie" denote a spherical source having a uniform intensity of one pyr; then we would have

$$\text{bougie} = 4\,\pi \text{ lumens.}$$

The symbols given in the last column of Table II have been proposed by M. Hospitalier, and he asks for criticisms. In the system of symbols and abbreviations recommended by the Congress, all quantities are denoted by oblique letters or script letters, and units and abbreviations for units by perpendicular letters. The proposed symbols, from their perpendicular character, will not harmonize well with the other symbols of quantity. Also they are already in use to denote vector quantities.

Discussion in New York.

The President:—I will ask Mr. Kennelly if he will kindly open the discussion on this paper.

Mr. A. E. Kennelly:—Mr. President and Gentlemen. I think we are much indebted to Dr. Macfarlane for bringing before us this evening a paper upon a subject of especial and rising importance. The deficiency in the nomenclature and in the measurement of illumination and light, is most noteworthy at the present time, when in electrical science we are developing a very praiseworthy accuracy in symbols, notations and definitions, and this contrast is so great, that it is surely time we were ashamed of the disparity, and were making serious efforts to improve the condition of affairs. The subject has been treated recently in the paper referred to by Dr. Macfarlane, namely that of M. Blondel in *La Lumière Électrique* of July 7th of last year, and all those who are interested in the subject can hardly fail to be especially interested in that paper. M. Blondel draws special attention to the great difficulties under which we lie in relation to discussion and expression, owing to the absence of any word or term to express the total quantity of light. It is true that in this Institute efforts have been made, notably upon the occasion mentioned in the first paragraph of the paper before us, when the attention of the Chicago Congress was initially directed to the deplorable deficiency in nomenclature in this direction. But it has been urged that the time was not ripe for maturing any system of nomenclature or of symbols, for the

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reason that we had no C. G. S. system of light. It is true that we have no C. G. S. system of light, and that our knowledge is so far behindhand, that we can hardly expect, even in the near future, to have a unit of light based upon the centimetre, gramme and second system. But the position I wish to take is, that we are as fully prepared now to define and name a unit of light as those who represent us may be in the far future, when the knowledge of this subject will be, we trust, much improved. Light never can be expressed in C. G. S. units for the reason that it is merely a physiological quantity. Of course, radiant energy is expressible in ergs, *i. e.*, in C. G. S. units. But so soon as we come to questions of practical importance, when we leave the domains of radiant energy, light necessarily becomes a physiological question, and if we desire to be very precise, we absolutely do not know that any standard sources of light, as we measure it or know it to-day, would have the same magnitude as the same source selected in the times of the Greeks or Assyrians. In other words, we have no evidence sufficient to assure us that the human eye is exactly the same instrument that it has been in previous centuries, or that it will be in centuries to come; and consequently it is impossible to define light practically, industrially, commercially, by any C. G. S. system of units. It is true that we may call so many ergs expended in such and such a wave length of such and such a frequency, as representing the unit quantity of light. But until we are supplied with sources of light which are entirely monochromatic, so surely must we mingle different wave lengths and frequencies; and then the difficulty comes as to how we shall compare different colors, and the only way in which that difficulty can be met is by the use of the eye, and the physiological factor enters into it. I trust, therefore, that the members will agree with me, that the time is now ripe for the adoption of some term covering and conveying the idea of "quantity of light." M. Blondel suggests the term "lumen." Call the unit what you please, it is of great importance. We are constantly making mistakes in our own thoughts, even those who are giving the subject close attention, and who are supposed to be conversant with its practical and technical details, while those who cannot and do not give the subject the attention it merits, are continually falling into pitfalls, on account of the absence of a phrase expressing quantity of light, and the absence of the series of ideas it would convey. Suppose we adopted such a term as "lumen," I think that the question as to how far the use of that term might become invalidated by subsequent improvements in photometry, would be eliminated in the way that questions concerning the magnitude of the ohm were eliminated. Electricians did not refrain from producing the ohm in 1861 because their methods were not sufficiently accurate. They produced the ohm to the best of their knowledge, capabilities and beliefs, and the ohm was correct within about one per cent., and subsequent at-

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tempts have improved upon the valuation then arrived at. So in the same way, if our methods of measurement of to-day are notably inferior to what they should be for a precise definition of a standard of light, some such term as "lumen" can be adopted as representing a specific quantity, and in future such measurements as may be made more correctly, and by processes more accurate than at present, can correct that quantity and render it with all the precision of the science that is to come. It is a matter of great difficulty for any men, or even for any institution, to move independently in a direction of this kind at the close of the nineteenth century, and I think we could not do better than call upon our colleagues, call upon allied societies in other parts of the world, requesting the expression of their opinion upon the subject as to whether the "lumen" is a good name, whether the "lumen" itself is a good unit, and whether any concerted expression of opinion can be arrived at on this point. The position I desire to take is that we are ready now, if we can only get concerted action, to adopt a unit which may be practically, industrially and commercially employed. I think it is eminently desirable that we should exclude the names of persons from such a system of units, and I think that M. Blondel's position in that respect, so far as he has shown it in Table II., is a correct one. It is to be noted that the unit of illumination that M. Blondel has taken, and which Dr. Macfarlane here represents, is that unit of illumination proposed by this INSTITUTE for the consideration of the Chicago Congress, namely the "bougie-metre," the bougie being the bougie-decimale or the one-twentieth part of the Violle standard. That produces an illumination which is the "lux" here suggested, namely the "lumen per steradian". That unit has therefore been long proposed, and it has already a name suggested for it. Mr. Preece about ten years ago suggested the name "lux," for the carcel-metre. The carcel-metre happened to be about the value of a candle-foot. In other words, the British candle gave at about the distance of a foot, the same illumination that the carcel lamp gave at the distance of one metre. Since that time, the carcel lamp has ceased to be a generally recognized standard outside of France, its place having been taken by the Violle, standardized by the Paris Convention of 1889, and the bougie-decimale, nominally one-twentieth part of the Violle is the recognized standard of luminous intensity to-day, although many secondary standards are in daily use; such, for instance, as the Hefner-Alteneck, the British candle and the new Reichsanstalt standard. There is one unfortunate fact concerning all the units that are suggested by M. Blondel, and that is that they are not all centimetre units; some are metre units. If you glance through Table II, it is evident that the metre enters as the standard of reference. That is an unfortunate fact which, perhaps, cannot be averted at the present time, for the reason that the "phot" having been already adopted by the International Congress of Photographers at

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Brussels in 1892; it is, perhaps, too late to select a centimetre unit for that purpose, and since the "bougie-metre," which corresponds to the "lux," has also been adopted practically, the system cannot be altered to suit the centimetre standard of length; the metre must run through it. The symbols, however, are unfortunate. The block symbols, in Table II., proposed by M. Hospitalier, as stated by Dr. Macfarlane, are already in very general use as denoting vector quantities, and some of these units are not vector quantities. It is therefore desirable, that a special notation should be employed which does not conflict with the vector notation, and it would be possible to put an asterisk or star, or some sign of notation attached to the ordinary capital letter to indicate that the unit of light was intended.

I hope, therefore, that the members will be in accordance with me that some action should be taken in this matter to endeavor to obtain a system of units for light and illumination, in which at least the unit quantity of light should be clearly understood.

THE PRESIDENT:—Gentlemen, you have heard the remarks of Mr. Kennelly. Do you wish to take up his suggestion now or will you discuss the paper first? I understand Mr. Kennelly to suggest that the INSTITUTE call on societies in different parts of the world to ascertain whether or not they have any suggestion to make concerning the use of the word "lumen" as a unit of flux or quantity of light. Should you see fit to do this it would seem to me that our regular Committee on Units and Standards would be a good committee to refer that to. However, it is for you to determine.

MR. TOWNSEND WOLCOTT:—I wish to make a few remarks only, about a portion of this paper which refers to what you might call "mho" units. There is worked out here a system which is entirely consistent with itself. But it seems to involve the same difficulty as the other notation. If we write $\tan^{-1}$, the difficulty seems to be that people mistake this inverse function for the reciprocal of the tangent. The only word of the kind proposed we have adopted so far is "mho," which is ohm spelled backward, which is reciprocal rather than the inverse function. It seems to me there would be danger that people would confound it in the same way. As to the expression, $\tan^{-1}$, it seems to be perfectly logical, only the principle is not carried out. The old English writers on mathematics, De Morgan—in fact, everybody so far as I know that has written on calculus operations, otherwise called the functional calculus, used that notation for all functions. If we write $\varphi\, x$; φ represents an operation, and then if we put an index to it, for instance ^{2}, that means the operation is repeated. If we put $^{-1}$, it would mean that that operation is performed the other way—an inverse operation is performed. The only trouble is when we go further. Most people when they write, $\tan^2 x$, mean the tangent of x^2, as Professor Macfarlane says. It might be perhaps well to have Professor

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Macfarlane's notation in addition to that. We sometimes have two notations for the same thing, and it does not do any harm. For instance, besides fractional indexes such as $x^{\frac{1}{2}}$, we also write that expression the other way: $\sqrt{x}$. If we put $\frac{1}{2}$ there: $\frac{1}{2}\sqrt{x}$ it would be just the same as x^2. We have two ways of writing the some thing.

This word "toof," instead of foot, is suggested to represent the reciprocal of a unit rather than an inverse operation, while Professor Macfarlane's reversed words represent operations performed—inverse operations instead of the reciprocals. It seems that there is just the same danger of people getting those two things mixed up as there is in the present notation.

THE PRESIDENT:—Is there any further discussion on this paper? Do I understand that there is a motion before the INSTITUTE respecting the suggestion that this matter be referred to the Committee on Units and Standards?

MR. WOLCOTT:—I move that the subject be referred to the Committee on Units and Standards.

THE PRESIDENT:—It is moved that the subject be referred to the Committee on Units and Standards, with the view of communicating with institutions in different parts of the world in order to ascertain their views as to the fitness for that use of the word "lumen" for quantity of light.

[The motion was carried.]

MR. DOUGLASS BURNETT:—Prof. Macfarlane is to be congratulated in adding to the results so carefully and searchingly obtained by Mons. A. Blondel. M. Blondel has emphasized for us the idea of flux of illumination. A perusal of the articles which have from time to time appeared on the subject of the distribution of illumination, shows the general application of the term "quantity of light," to the expression of this idea, with the omission of the term "radiated per unit time."

In considerations like the present, we must distinguish between units for practical, and for theoretical application. Practically we are concerned simply with (*a*) the intensity of the source of light, and (*b*) the brilliancy of illumination of the exposed surface. Theoretically we must have in mind the operations in progress in the space between the source and the illuminated surface.

In considering the radiation of heat from cooling bodies, which, being at high temperatures, are sources of energy, or the radiation from hot bodies in which the heat is continuously supplied, we arrive without difficulty at the idea of a flux of energy from such bodies; and we ordinarily speak of the number of calories or B. T. U. radiated per unit time through a certain space from a surface of unit area. In the case of the conduction of heat within a solid medium, the same terms may be used.

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Then by the use of the mechanical equivalent of heat, these numbers are transmuted to energy units—kgm. or joules.

In light however, it is not ordinarily so evident that there is a radiation of energy from a luminous body, or a reflection of energy from reflecting bodies, and in consequence we use in photometry the candle as the unit of intensity of a source, or the candle foot, or foot candle, as the unit of light received on a surface. The idea that in the space surrounding a source of light, there is a continuous passage in straight lines in all directions of that which may be transformed into mechanical work, is not usually apparent in such considerations.

As it stands, M. Blondel's paper is not complete, in that it fails to include the ideas which Dr. Macfarlane has summarized in Table I. The idea of the distribution of energy in the space surrounding a luminous source lies at the root of this table.

It is to be hoped that at no very distant date illumination will be capable of being expressed in absolute units. We note with pleasure Prof. R. A. Fessenden's suggestion on page 112 of the last volume of our TRANSACTIONS, with reference to the visual effects produced in various parts of the spectrum, when the radiation of each wave length is regulated in amount to equal one watt; also the results obtained by Prof. H. F. Weber, given to the Berlin Academy of Sciences in 1888, which included a formula expressing the relation between the intensity of any selected homogeneous radiation, the corresponding wave length, the temperature and the quality of the radiating substance.

It seems quite possible that with certain data supplied, we could at present express in energy units any amount of light which may pass through a given space. This it seems might be done by combining the efficiency of the source (the ratio of luminous to total radiation) with the total energy supplied. Thus in the case of sunlight at the earth's surface, Werner Siemens has given its luminous efficiency as 25 per cent. Langley has measured the radiation received from the sun at zenith to be 133 foot-pounds per square foot per second; also Young has given the zenith illumination as 60,000 metre candles. We have here by reduction 44.76 watts of light received per square foot, or 482 watts per square metre, in the form of light. That is, there is a flux through a square cm. of cross-section of the ray of light equal to 48,200 ergs per second.

Similarly we might express the light energy radiated from a 50-watt 16-candle incandescent lamp with 5 per cent. luminous efficiency (Merritt). We may thus find that in order to secure the same intensity of illumination as is produced by the sun, as above supposed, the filament should be placed at the center of a sphere of 2 cm. radius. In that case, light energy would be received at a density of 482 watts per square metre on the inner surface of the sphere.

The light produced by a gas flame might similarly be estimated in absolute units, by taking into account the calorific power of

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the fuel, its rate of burning, the mechanical equivalent of heat, and the luminous efficiency of the flame, which is approximately 5 per cent.

Considering further an arc with 10 per cent. luminous efficiency (Nakano) we may determine the amount of energy in watts or joules per second, radiated as light from this source.

Having once obtained the radiation from a source in absolute units for several typical cases, photometry as ordinarily carried out will give the value of the energy of any measurable source. Thence we may obtain measures for each of the items enumerated in Professor Macfarlane's Table I.

II.

The English unit in common use corresponding to the pyr, is the candle. We have the definition—

lumen = pyr-steradian.

The "lumen" is similar to the candle-steradian. We have in the English system, however, no unit similar to the "lumen." If we attempt to express the idea embodied in this name we will find that our sole means of expression is the foot-candle per square foot; this, however, is not an appropriate name, inasmuch as the light of one foot-candle shining upon two square feet, is equal simply to one foot-candle *over* two square feet. While the amount of radiation equals theoretically two foot-candles per square foot, yet this statement would not be applicable to the case of the concentration of light produced by a projector, for the term may only refer to the intensity over each square foot. The illumination in the above case is not two, but one foot-candle per square foot. The statement can only be made definite by the use of some such term as candle-steradian.

III.

The word "ray" is capable of exact mathematical definition just as is the magnetic term "line of force." The latter represents unit intensity of magnetization; the former may represent unit flux of light, or intensity of radiation passing through unit cross-section. A light of certain candle power may be stated as emitting a certain number of rays per square cm. at unit distance, as a magnetic field may be said to be traversed by a definite number of lines per square cm. The parallel beam from a projector might be referred to as being of density so and so many rays per square inch or centimetre.

IV.

While on the subject, we might take it upon ourselves to point out that the space candle-power curve as ordinarily found in papers stating the results of photometric measurements, does not carry the idea which it is intended should be given. In case

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of a vertical candle power curve of an arc lamp, if the intensity under various angles with the horizon, be reduced by means of the formula: Intensity of illumination (foot-candles) = intensity (candles) at source ÷ (distance)^2, we may get vertical curves showing the actual illumination produced at the various points in the space surrounding the arc lamp. Such curves drawn through points of equal illumination may be called "isophotals."

If a map of such curves be made, the curve referring to values of 1, 2 . . . . etc., foot-candles, and a line representing an illuminated surface in section, be drawn to cut such curves at a definite distance from the lamp, the amount of light to which these curves individually refer will be incident upon the points at which they cut the lines so drawn; and therefrom may be drawn, if so desired, another curve, representing these various values of illumination as we proceed from point to point of said surface.

In conclusion, I may state my belief that the expression of such ideas as are found in both Dr. Macfarlane's and M. Blondel's papers cannot fail to be of inestimable value in the clarification of photometric conceptions.

[Communication Received After Adjournment.]

Mr. Clayton H. Sharp (*communicated*):—In regard to what Dr. Macfarlane says concerning the name of functions which are reciprocals of already named functions or units, it seems to me that we must not lose sight of the fact that words are essentially *sounds*, which among civilized people are represented by a certain combination of symbols. In forming a word by inverting the order of the letters of a known word, we reverse the historical and logical process of word formation and violate all etymological principles. If we wish to express the fact that a relation exists between a unit and its reciprocal, we should give to the reciprocal a name, *i. e.*, a sound, that will suggest the relationship. For example, the symbol "sin." stands for a particular word. We can, according to phonetic laws give to the symbol "nis." a sound; but this word will bear no relationship to the word represented by "sin." The word which we might imagine to be represented by a "candle-toof-toof" is just as good English as it is Choctaw, and no better. Moreover, the appearance of a word formed by inversion, conveys no idea to the brain unless we cultivate the Chinese art of reading backward. That this so-called "principle" has its limitations is evident, if we suppose that we wish to form, according to it, a name for the reciprocal of the "watt."

The table of c. g. s. units of radiation which the author gives is very interesting. The only thing lacking is a method of establishing a c. g. s. unit of luminous intensity, and unfortunately, we seem to be about as far from that as ever. The units pro-

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posed by M. Blondel are undoubtedly logical, and their names are well chosen. The chief objection to them outside of that urged by Dr. Macfarlane is, it seems to me, that we have little or no use for them. We do need a name for the unit of luminous intensity, and, perhaps a simple, rather than a compound name for the unit of illumination would be desirable. Further than this in the naming of units, it seems to me that we need not go. The other units are used so little that it would not be burdensome to employ compound names for them, and it is always to be remembered that a multiplicity of abstract names invariably causes confusion.

Discussion at Chicago, January 16th, 1895.

[Mr. S. Arthur Rhodes in the Chair.]

Prof. W. M. Stine:—I would call attention to a movement that is now gaining force amongst the photographers of the country. As the editor of one of the leading photographic journals recently expressed to the speaker, "We are trying to get rid of our worst enemy, daylight." Since daylight is such an uncertain factor in photographic work, the arc lamp is fast coming into use to replace it. Photographers are thus endeavoring to obtain a unit light or condition of exposure for their plates. They have a problem before them similar to that encountered in electric illumination, but one whose applications simplify it to some extent. I mention this fact because the paper just read has some bearing on their investigations.

As an attempt to point out the conditions and relations of unit radiation from a light source, the paper has great merit, and, while the mathematical relations have been so fully worked out by the author and others, yet the attempt to assign a nomenclature to certain unit conditions seems perhaps premature. A portion of the title seems unfortunate. The paper does not deal with the unit of light as in any sense applicable to illumination, but the unit conditions of radiant energy, as applicable to a hot-non-luminous, as well as to a hot-luminous source. To render it applicable to purposes of photometry, the question of the amount of radiant energy from the accepted unit for illumination under the unit conditions here laid down must be determined. It seems that this after all is the vital question, and the subsequent ones of the relations of space radiation could readily be obtained from well-known properties of solid angles. All through the discussion a standard of illumination seems presupposed. But here rests the whole matter. We seem almost further removed from a light standard than ever before. It is the physiological action, or peculiarities of the eye which causes the difficulty. The eye is concerned with the quality of the light rather than the intensity of the radiant energy from a source. Even should we arrive at a standard for illumination, which would evaluate the effect of

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a given light on the eye, and express this unit in terms of the energy involved, we could by no means employ the conclusions here expressed in such a general sense as to make them applicable to all lights.

The quality of a light being its larger factor, lights of a different character cannot be compared along the lines of simple energy relations; at best we can only compare a single light as affected by space relations. Even should the "light of the future" be realized, we must still hold it capable of variation and quality. The conclusion is, that the attempt to establish unit space and surface relations for purposes of nomenclature is not well founded. Neither can we hope it will gain general acceptance. The whole matter seems to belong to the sphere of radiant energy, and it is a question of pure physics rather than one applicable to electrical illumination. As such, the conditions have already been worked out, and can readily be applied in the restricted sense already pointed out, when occasion demands. It seems ill-advised to confuse a subject dealing only with the pure physics of radiant energy by the application of such terms for units as apply only to questions of illumination, involving but indirectly those of radiant energy.

The desire to establish units for the evident purpose of nomenclature has here reversed the usual and logical order. It seems reasonable to await the establishment of a given unit condition before attempting its nomenclature. We must first of all attain a unit condition of light, or, rather of illumination, if the unit is to have any influence. Then it is probable that the naming of the unit would be all-sufficient. Its space and surface relations can be dealt with by the aid of the usual mathematical relations, without encumbering the process with useless nomenclature.

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A paper presented at the Ninety-third Meeting of the American Institute of Electrical Engineers, New York, President Houston in the Chair, and Chicago, Mr. S. Arthur Rhodes in the Chair, January 16th, 1895.

THE BEST METAL FOR FIELD MAGNET FRAMES.

BY ALTON D. ADAMS.

Cast-iron, cast-steel and wrought-iron being the materials at our command for field magnet construction, it is an important question to the engineer and manufacturer, which will produce a dynamo of given capacity, speed, efficiency and working qualities at the least cost.

I am not aware that any of the works on dynamo construction attempt a definite answer to this question, and the practice of builders is by no means uniform. Economical points of saturation requiring about the same magnetizing force per unit of length in each metal, are for cast-iron a little under 40,000, cast-steel, 70,000 to 80,000, and wrought-iron about 90,000 lines per square inch.

The cost of cast-steel is fully equal to that of forgings in simple shapes, and as it lies between cast and wrought-iron in magnetic qualities, the cost of machines made with it will be between those of cast and wrought-iron. A comparison will, therefore, be made between the cost of the latter two.

To be fairly compared, machines of different materials must be equal as to magnetic flux in field and armature cores, ampere-turns on armatures, field ampere-turns required in air-gaps, and as nearly as possible in magnet frames, watts used in windings, and be of the same capacities and speeds.

Taking wrought-iron at a saturation of 90,000 and cast at 40,000 lines per square inch, the section of an equivalent cast, will be two and one-quarter times that of a wrought frame, and as the length of the cast-iron frame must be a little greater to give enough winding length, its weight will be about two and one-half times the wrought. A saving is thus at once made in

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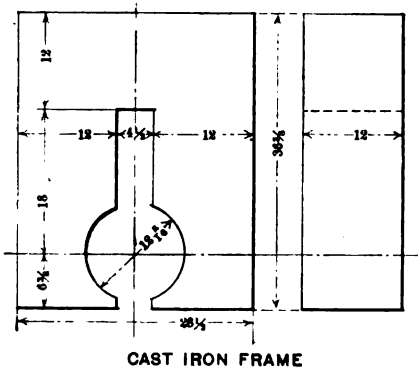
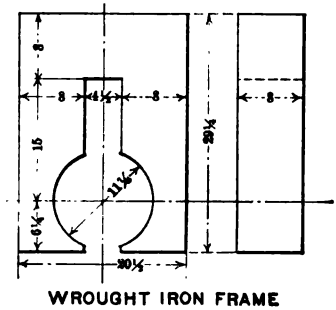
favor of the wrought magnet, as forgings can be had per pound for much less than two and one-half times the cost of cast-iron.

The same number of ampere-turns and watts being required for the coils of the cast as the wrought-iron magnet, and the weight of wire varying as the square of its length, the coils for the cast-iron frame will be much heavier. The armature core may have the same diameter in each frame, but must be longer in the cast frame so as to come under the pole-pieces, thus materially increasing its weight.

As for the same resistance, the weight of armature winding increases as the square of its length, considerably more wire is required for the armature core of the cast-iron machine. In addition, the purely mechanical parts, shaft and base must be larger



CAST IRON FRAME



WROUGHT IRON FRAME

and more costly in the cast-iron machine because of the greater weights they have to carry.

To illustrate the difference in cost of construction, the following data of two machines is presented, each having capacity of 25 K. W. of 1,275 revolutions per minute, the same winding losses, the same ampere-turns on armatures and field ampere-turns in air-gaps equal to about twice the armature ampere-turns active at the pole corners.

The air-gaps and armature cores of each machine are crossed by 4,320,000 magnetic lines, and allowing a leakage of 25 per cent. the field core must furnish 5,760,000 lines.

A wrought-iron field to carry 5,760,000 lines, at 90,000 per inch saturation, requires a section of 64 square inches, which is provided by a core of 8 inches square and a cast-iron field at 40,000 lines per square inch requires a section of 144 square inches provided by a core 12 inches square.

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Allowing sufficient length for magnet windings, the same air-gap resistance and an armature core of 11 inches diameter for each of these frames, their dimensions will correspond to the above drawings.

The weights of these frames are

Wrought-iron frame	1020 lbs.
Cast-iron frame	2730 "

For work as shunt motors, the wrought-iron machine requires 11,000 ampere-turns in the air-gaps and 2,000 in iron, the cast machine 11,000 ampere-turns in air-gaps and 3,800 in iron.

With 440 watts expended in field coils of each machine, an average length per turn of 38 inches in the coils for wrought-iron, and 54 inches in the coils for cast-iron, the weights of these coils are

Wrought-iron machine	133 lbs. copper.
Cast-iron machine	340 " "

The drum armature for the wrought frame is 11 inches diameter and 8 inches long, that for the cast frame 11 inches diameter and 12 inches long, without allowance for shaft hole.

The weights for armatures are

Wrought-iron machine	211 lbs. disks.
Cast-iron machine	316 " "

With a loss at full load of 490 watts in the armature winding for wrought-iron machine, and 464 watts in the armature winding for cast-iron machine, these windings require in

Wrought-iron machine	49 lbs. copper.
Cast-iron machine	71 " "

The above indicates plainly the great saving of wrought over cast-iron in dynamo construction.

From the users' standpoint the wrought-iron machine seems preferable on account of its lesser weight and bulk, this difference being especially marked in machines for direct connection to engines, and other purposes where slow speed is necessary.

Discussion in New York.

The President:—I will ask Prof. Crocker if he will open the discussion on this subject.

Prof. Francis B. Crocker:—Mr. President and gentlemen, I regret that Mr. Adams did not carry this subject further, because it is certainly interesting, and is also very important. The principal comment would be in regard to treating the subject more fully. But I note one or two points. In the first place, he dis-

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poses of cast-steel in a manner which I think is hardly worthy of it. I mean to say that I think it deserves better treatment; because, in the first place, the cost of cast-steel is less at present market prices than that of forgings of the same shape. For example, cast-steel can be obtained in ordinary sizes and shapes, and in quite complicated shapes at four cents per pound. Drop forgings would probably cost something like six or seven for similar shapes and similar sizes. To be sure we can get plain wrought-iron in bar shape, for example, or cylinders of wrought-iron, for two or three cents a pound; but before these were gotten into shape to be used for dynamos and motors they would cost considerably more, on account of the machine work, and the fitting on of the pole-pieces and various parts. The raw material might be fairly cheap, but before it was gotten into the finished shape, I think it would cost more than the cast-steel, to say nothing of the complication and disadvantage of having a machine made up of several parts instead of one integral casting. Consequently, I should say that cast-steel should be put ahead of wrought-iron as a material for the field-magnets of dynamos and motors.

I would also like to call attention to the fact that the terms "cast-steel" and "wrought-iron" are arbitrary. We are accustomed to consider wrought-iron as a certain material, and cast-steel as quite a different material; but those names are based usually on the processes of production, and not on the chemical composition or physical properties of the metal obtained. I do not think that point is fully realized by those who have not made a special study of it. Mr. Tesla called my attention to the fact several years ago that "steel" may be actually purer iron than the ordinary wrought-iron of commerce. Consequently it is really cast wrought-iron, and therefore we might expect, and we do actually get about the same magnetic permeability for cast-steel as for wrought-iron, simply because it is nearly pure iron in both cases, the impurities being about the same. Of course very pure wrought-iron is purer than so-called cast-steel, but ordinary wrought-iron is not. The old idea was, that steel consisted of iron containing about one per cent. of carbon. Of course, to-day, that is not necessarily so, because it is possible to get mild steel which contains only a very small fraction of one per cent. of carbon. The advantage of cast-steel is that it can be obtained in almost any desired shape. I will cite only one case to illustrate where cast-steel could be employed, and is employed very successfully, where it would be out of the question to employ wrought-iron, and that is in the box type of railway motor. It is almost inconceivable that such a machine could be made with a wrought-iron field magnet; whereas cast-steel answers admirably, and boxes with sides only half an inch or so in thickness, can be made very successfully and are just exactly what are required. Less complicated shapes than that might be made in wrought-iron, but usually they can be made much more easily in cast-steel, and even the ordi-

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nary magnets with pole-pieces suitable to form the field space can be made in cast-steel more easily than they can in wrought-iron. Consequently it seems to me that cast-steel is really the thing to compare with cast-iron as a material for field magnets. It is rather convenient that if we make a square, or circle, or other similar figure of one and one-half times the linear dimensions we get an area two and a quarter times as great. Consequently this ratio is exactly right to make up for the relative permeabilities of cast and wrought-iron, and in designing and comparing dynamos and motors, this is rather a convenient point. It is contained in this paper, but it is so simple that it is worthy of special notice.

A point that Mr. Adams does not touch upon is the making of composite machines. By that, I mean a machine, for example, with wrought-iron or cast-steel magnet cores and with cast-iron yokes or base. In many cases that is a great advantage. It is a great advantage because you want the weight in certain places, and the comparison he makes, where cast-iron is so much greater in weight than wrought-iron, becomes converted from a disadvantage to an advantage. In my opinion, and I advocated it before this INSTITUTE some years ago,[1] a certain weight in a stationary machine, particularly if that weight is placed near the ground, is positively desirable, and a cast-steel frame throughout, in my opinion, would not make as desirable a machine as one with a certain amount of cast-iron put in the base as ballast, so to speak. That involves machine work and complications, which I said was somewhat objectionable; but in most cases it is unavoidable. No one is likely to make the entire machine, including bearings, base and field-magnets, in one piece, and if we are going to make them of two pieces, it is just as well to construct the magnet proper of a material having the highest permeability; and the base, yoke, bearings and other parts, where permeability is not of much consequence, can be made of cast-iron with advantage.

Now there are certain peculiar designs of machine, where a certain one of these three materials may be almost essential or desirable, and it will be well, I think, if a somewhat more practical and real case were given than that illustrated in the figures. The form represented here is simply an ideal or abstract magnet, and the rest of the machine is not shown, and when you come to design the entire machine, it might seriously modify the mere geometrical facts that the magnet shown would indicate, and as an illustration, if for no other reason, I think it would be well if the paper were supplemented by the actual design of three or four practical machines. Then I think you would find that the case is not quite so simple as it appears to be in the paper. I presume Mr. Adams' intention was only to give a general comparison, and not special cases, but it would certainly add to the

1. TRANSACTIONS, vol. viii., p. 188.

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value of the paper if at least one special case were considered and carried out.

MR. RICHARD FLEMING:—The casual reader of Mr. Adams' paper would be likely to get the impression that there was no other metal than cast and wrought-iron available for dynamo construction. It is not a discussion of the "best metal" for the purpose, as much as it is a comparison of the relative advantages of wrought and cast-iron. Dynamo builders long ago found that wrought-iron was far superior to cast in point of cost and construction, but this is about the only advantage it has over cast-iron, for a dynamo or motor of cast-iron will work equally as well as any wrought-iron machine if the same laws are followed out in the design.

It will be heavier, of course, but that is only a matter of freight and cartage. After it is set up, it matters little to the user whether it weighs one ton or two, if it does its work as well. The extra weight in this case is an advantage, for the machine will be less liable to vibrate on a light foundation.

I do not agree with the author that the armature must be longer in a cast frame. I do not see why any extra length should be allowed so as to come under the pole-pieces. There is no difficulty in designing a machine to have an air-gap area at least equal that of a cast-iron field core with an induction of 40,000 to the square inch. And as 40,000 lines to the square inch in the air-gap is very high, the armature will of necessity have to be made long enough to reduce the induction in the air-gaps to a practicable limit. About 20,000 (square inch) is the average induction in the air-gap. This certainly will not saturate the pole face, and as a wrought-iron frame admits of no higher induction in the gap, there is no reason why the armature should be shorter in the wrought frames.

Going back to the question of the best metal for magnet frames, and allowing that the cost of production of the finished article is the only consideration that governs the choice, there is no doubt in my mind that cast-steel is far cheaper than either wrought or cast-iron. I have not jumped at the conclusion either.

I have made a large number of designs of machines allowing the same efficiency, speed, etc., and found from an impartial consideration of the matter that steel gave the best results. This is due more to the facility with which it lends itself to be moulded into any desired shape, than to any inherent quality as a magnetic material, though between the best wrought-iron and the *best* cast-steel there is little difference in this respect, and the price per pound will be in favor of the steel. The weight of metal in either case for frames of the same capacity will be about the same. The chief advantage of steel will be the small cost of machining, and the shorter time it takes to put it through the shops. This is due to the fact that a frame can be designed so

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that when it comes from the foundry there is very little tooling to be done on it, which is a very large item in these days of sharp competition. The finished machine, too, can be made to look better at less cost, and its working qualities will be as good, if not better.

Dr. Samuel Sheldon :—It seems that data of the magnetization curves of wrought-iron are few. Some one, I think, perhaps, it was Mr. Steinmetz, uttered a suspicion that Hopkinson's iron was remarkably good. Hopkinson's results crop up in all our papers on magnetic phenomena. I have tested a number of samples of cast-steel from different iron firms and I find that you can get a very good quality of open-hearth steel for four cents a pound. We have quite a number of tests on steel, made at Cornell. I have found three samples of steel which lie higher and show a better permeability than the samples of steel mentioned in the Cornell paper. I have found one sample of steel which runs at one portion of the curve—to be sure, it is at a rather high magnetizing force (H = thirty-five)—above Hopkinson's curve for soft iron. Some of the forms of steel do not run as high; for a magnetization of, say, 15 to 25, they run from 11,000 to 12,000. Other samples are from 14,000 to 15,000 for those same magnetizations. So it seems that when we come to consider the ease of manufacture and other points in favor of cast-steel, we certainly cannot throw up the lack of magnetic properties in the face of them.

I should like to know if there are any other members present who have made measurements on wrought-iron which yield inductions as high as Hopkinson's iron.

Mr. Kennelly :—In relation to the question of the permeability or reluctivity of wrought-iron and steel, I never have seen any numerical values obtained by Dr. Hopkinson. I think that Dr. Hopkinson's values, as noted in various papers, are taken from a curve given in his original paper, and I have seen it stated in some of the quotations that they were taken from that curve. In fact, there was an ascending and a descending curve which differed materially. I have made a number of measurements of the reluctivity or permeability of samples of wrought-iron and cast-steel, and have never found any sample of wrought-iron superior, or even equal to the quoted values of Hopkinson's iron in the earlier parts of the curve, that is to say, between three gilberts and ten gilberts per centimetre; but from ten onwards, the samples that I have tested have shown a permeability almost exactly equal to that of Hopkinson's, and some samples of steel that I have tested have been superior to the iron of Hopkinson by a small amount, in the same way that Dr. Sheldon describes. While, however, the reluctivity of good wrought-iron is very fairly uniform in different samples, the reluctivity of different samples of cast-steel frequently differs materially.

Mr. Gano S. Dunn :—I think one reason, perhaps, why such

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good curves have been obtained of wrought-iron is because most of the tests that have been made have been made on very small samples, on wires of a few millimetres in diameter, and I believe that such wires would be found to be of higher magnetic quality than a large bar, which is what we have to deal with in the actual construction of the machine. My experience with wrought-iron has been that it has never come equal to Hopkinson's curve, and it frequently falls nearly ten per cent. below it throughout.

Mr. James Burke:—I note that Mr. Adams has compared these machines on the basis of the same total watts lost in the magnet coils. It seems to me that one point which might be considered, is a comparison on the basis of the same heating of the coils, for in the case referred to, on account of the very much greater radiating surface in the cast-iron machine, its windings would run very much cooler. The weight of copper in the magnet windings of the cast-iron machine would be reduced considerably if the same increase in temperature as in the wrought-iron machine is allowed. The actual loss in the magnet winding would be increased on account of this reduction in copper, but as the armature core loss, in the machines Mr. Adams has compared, is much less in the cast-iron machine, for it has a lower density in the core, the efficiency of the machine would not be affected materially.

Mr. Adams points out that the armature has to be very much longer in the cast-iron machine. If the common practice of having a gap density in the neighborhood of 40 to 60,000 is followed, it would seem unnecessary to have a longer armature in the cast-iron than in the wrought-iron machine.

It is sometimes a great advantage in machines with toothed armatures, to use laminated pole-pieces. In cases of this kind the cost of construction can often be reduced by using a yoke of cast-iron and casting the pole-pieces into it.

Another condition, wherein cast-iron has some advantages as to cost of material, exists in the magnet yokes of large machines with many poles, in which the section necessary for mechanical reasons is also sufficient to allow a normal density for cast-iron.

I also wish to call attention to the densities that Mr. Adams states for cast-steel, as it is not unusual practice in steel magnet cores to run the density up to 90 or even 100,000.

Mr. W. L. Bliss:—It seems to me that the greatest advantage to be gained from the use of wrought-iron and steel in the manufacture of field magnets for electrical machinery, would lie principally in the construction of small machines. We are almost invariably confined to the bipolar type of magnet in dynamos and motors of small output, and this type of magnet must necessarily be constructed of material of high permeability. In a small machine, the relations existing between the various dimensions are totally different from those of machines of larger output. For instance,

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in a small dynamo, the air-gap being enormously larger, simply for mechanical reasons, than is required to secure regulation and sparkless running, a very excessive magnetizing force is required on the fields, and this in turn necessitates the use of a high grade of wrought-iron or steel. When we come to build a larger machine—Mr. Adams speaks here of 25 K.W.—it is a question whether we continue in the bipolar type, or what seems preferable to me, pass to multipolar construction. If we adopt the latter, I think we shall find that after calculating the armature dimensions according to the best modern practice, and allowing sufficient air-gap to secure satisfactory operation, the cross-section of our field magnet and poles will be great enough to admit of the use of almost any metal whether it be wrought-iron, cast-iron or steel. The length of the magnetic circuit in a multipolar machine is always smaller relatively to the other dimensions than in a bipolar, and hence the portion of the magnetic circuit that will require the most attention will be the air-gap. This latter will consume such a large percentage of our magnetizing force, that it matters little what slight reluctances be introduced into the magnetic circuit, and indeed if we employ a construction like that mentioned by Mr. Burke where laminated pole-pieces are cast into cast-iron frames, although such a construction introduces a reluctance at the joint, we need not allow this matter to trouble us, since the ampere-turns required for the air-gap constitute so large a percentage of the total field excitation. Consequently in large machines we are not compelled, either on account of efficiency or first cost, to introduce expensive forgings or even steel castings. It will simply be a question of weight. By using the metals of high permeability we can somewhat reduce weight and bulk. In large machines the air-gap has to be so abnormally increased, beyond that required for simply mechanical purposes, and especially in multipolar forms, that in almost any well-designed machine with a toothed armature, it would be possible to take all the conductors out of the slots and distribute them around the circumference of the armature, and still leave plenty of room for banding and clearance. So the question of using steel, wrought-iron or cast-iron, for our field magnets would depend principally on the size of the machine. I think one criticism that could be made on the form of machine depicted in these drawings is that it is perhaps a little antiquated. It does not seem to me a very economical design of field magnet for that output.

PROF. CROCKER:—It seems to me that cast-steel is not the expensive metal that the last speaker implied. Cast-steel can be obtained for four cents per pound, and it is equivalent to fully twice the cross-section of cast-iron. Now, we cannot get cast-iron for less than two cents per pound. Consequently, we are exactly as well off with cast-iron or with cast-steel, so far as the mere cost of the magnet is concerned. And furthermore, to get the same number of ampere-turns with cast-iron it requires about 41 per cent.

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more wire than on cast-steel. I, therefore, fail to see that the use of cast-steel is an expensive luxury. It seems to me that it is truly the cheapest material for the purpose to-day. We not only get the advantage of the high permeability, but also secure actual economy in wire, and a smaller and better machine in every way.[1]

MR. ADAMS:—I need hardly say that this little paper was not intended to be exhaustive, or to say all that might be said on the subject.

I have often heard ideas expressed similar to those advanced by one speaker to-night, to the effect that cast-steel or wrought-iron makes an expensive, efficient machine, and cast-iron a cheap but rather inefficient machine, and that idea is one which this paper was intended, if possible, to set aside, as I believe that for a given efficiency, speed, capacity and condition of working qualities a high permeability metal, as wrought-iron or cast-steel will make a cheaper machine, cheaper as to the cost of the frame, cheaper as to the cost of the field wire, and cheaper as to the cost of the armature wire than will a low permeability metal like cast-iron. Any way that I can figure it brings that result.

I will say with reference to the remark of Professor Crocker, concering the relative cost of cast-steel and wrought-iron, that our difference of opinion on that lies largely in the fact that I must have found a cheaper place to buy wrought-iron than he has. As I said in the paper, in simple shapes, such as are required and used for bipolar machines by many parties, wrought iron forgings can be had at as low price per pound as cast-steel. I have never been able to get steel castings that would come within $\frac{1}{16}''$ of the dimensions given on the drawing to the pattern-makers. But one can get rough machined forgings within $\frac{1}{16}''$, and that is, perhaps, not too much leeway to allow in field spools to slip over the cores, and it saves machining in the shop. That I consider a very considerable advantage, as if field spools are desired to fit accurately over cast-steel cores, you must machine the cores in any steel that I have been able to get hold of. Of course, my experience does not cover many makes, and there may be steel castings that come to within $\frac{1}{16}''$ of given dimensions.

With regard to the type of machine taken here as an illustration, I must disagree with some of the remarks that have been made, because I have certainly taken here, if I understand the matter, a type of machine which is made by more prominent manufacturing concerns than any other in the world—the ordinary bipolar, straight, upright, downright field magnet I do

1. In the paper already cited (TRANSACTIONS, vol. viii., p. 190) I stated that "The supposition that cast-iron is cheaper than wrought is a fallacy, as its permeability is as much below that of wrought-iron as is its price, both being about one-half." The same is now true of cast-steel, which at that time (May, 1891), however, cost about twice as much as at present, and was rarely used for the purpose.

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not know of any single type that is made by prominent concerns the world over as generally as that. I fail to see anything ideal, as opposed to practical in this design.

In the wrought-iron design, I have made quite a number of machines running up into the dozens, of about that same section and weight of magnet and same capacity, and from the knowledge that I have of the practice of other concerns in this country and in Europe, I am very certain that a great many machines have been designed and are operated to-day that correspond very nearly as to wrought-iron field-magnet with that I have shown. I have also, I am sorry to say, seen some field magnets made by prominent concerns that correspond very closely to the large cast-iron one.

The criticism has been made that the armature should not have been lengthened out for the cast-iron frame. If any gentleman can show how he will shape that frame to get the magnetism from it to the armature core without making that armature core bigger, then the criticism will rest on a solid foundation. I confess I do not know how to do it in a satisfactory manner. It might be done by flattening out the frame and making it only 8″ wide, and then it would have to be big enough the other way to give the section of 144 square inches, which it strikes me would make at least an odd shape of field magnet.

With reference to the magnetic qualities of wrought-iron I may say that in building several hundred machines of wrought-iron I have in almost every instance, where I have had well hammered forgings, which are of course essential, been able to get results indicated by Hopkinson's data. My experience with cast-steel, while I have not used nearly as much of it as many gentlemen who have spoken here to-night, has been, that one cannot rely on getting as high permeability with it as in well hammered forgings. It may be, of course, that my experience with cast-steel has been unfortunate, but I have found it rather an uncertain metal in the matter of permeability. If we have to deal with any metal that is certain, I think it is wrought-iron—I mean iron well hammered, not bar-iron bought in the open market, but iron that is hammered up from scrap until it is clean, so that it does not show any bad seams or anything of that sort.

With regard to the adaptability of wrought-iron and cast-steel for machines of intricate shape, I want to say that it is not the purpose of this paper to attempt to balance the comparative desirability of simple and intricate shapes. There is no question if it is desirable to build machines of intricate shapes, as many think it to be, cast-steel is the metal to use. But for the simple shapes in which forgings can be had, at as low price per pound as steel castings, the higher permeability, close dimensions and ease of machining make forgings more desirable.

With regard to the point taken by one gentleman that we might have allowed a greater loss in the field-magnet coils of the

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cast-iron machine, that point of course is well taken in a sense. The builder of a cast-iron machine having gone to a good deal of expense in other ways would naturally try to save himself a little by using more watts in the field coils. But the comparison is based on the same coil loss all around, and that is why the figures are carried out on that basis. It is a noticeable fact that some very prominent builders in this country and in Europe, in spite of the very desirable qualities of cast-steel, are using a great deal of cast-iron and wrought-iron in magnet-frames, some of them in very large multipolar machines. I do not myself see any economy in the use of stamped sheet-iron, except where it is necessary to prevent heating of pole-pieces, and from my point of view, that necessity had better be avoided.

It certainly would be cheaper to cast or even to bolt solid pole-pieces of wrought-iron, into their proper places on the inside of multipolar frames, such as I suppose were referred to, than to use stamped sheets for the purpose.

Mr. Fleming:—I would like to add a word in regard to the space necessary to allow for clearance in field spools to go over cast-steel cores. I would say that for moderate sizes, say 12″ in largest dimension; ⅛″ is all that is necessary. A small clearance here is not a disadvantage, as it admits of a considerable circulation of air between coil and core, thereby increasing the radiating surface of the coil.

Referring to the design shown in the paper—of course if we confine ourselves to square sections (upright and downright as Mr. Adams expresses it), we cannot improve on the design very well, but there is no necessity of making the cast-iron frame in a single casting as the sketch calls for. In a machine of this class, a better plan would be to make the magnetic circuit in two or more parts, having the field cores of circular section, thereby reducing the mean length per turn of wire embracing them, which would be a considerable saving, and extend the pole-pieces sufficiently to embrace the armature, the length of which is determined by the polar span, and the density of magnetization, both of which should be about the same, whether wrought or cast-iron be used.

It is practically out of the question to use forgings for multipolar dynamos unless in conjunction with either cast-iron or steel. When used with cast-iron there is trouble from oversaturation at the junction of the two metals, due to the lower permeability of the cast-iron, unless special precautions be taken to increase the area of contact. This need not be considered if cast-steel is used.

The most economical plan is to use steel throughout, making the magnetic frame in as few parts as possible. As regards the permeability of cast-steel I have experienced no difficulty in getting an induction of 13,000 per square cm. This could be exceeded were it not necessary to allow a little for blowholes and slight imperfections in the castings, though for castings from the

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best manufacturers nowadays it is hardly necessary to make any allowance for blemishes.

I do not consider it policy to use higher induction than 13,000 in the average wrought-iron forging. In multipolar machines, if weight and compactness of design have any consideration at all, the advantage is decidedly in favor of cast-steel. The total weight of the machine will be less, the mean length of the magnetic circuit will be less, and by getting any desired section for the field core you will be able to make any compromise that will be deemed necessary in the design of the machine. Kapp has said truly that a dynamo is a compromise all the way through.

Mr. Frank M. Ashley:—Relative to the difference in permeability of cast-steel, I find in my experience, that the soundness of the metal affects the permeability and that in getting large steel castings, very often bad blowholes are found where we least expect them. If they exist near the surface of the armature, in the pole pieces, they naturally make a great difference in the density of magnetism at those points. It is necessary to have the poles free from blowholes to get the best results, and in ordering castings for such purposes, I find that by specifying that the metal shall be taken from the center of the run, the castings are usually more uniform and more free from blowholes. It is usually where the metal is taken from the last part of the run that the worst blowholes occur. I have at present a couple of castings with large blowholes, found just below the surface when they were machined. Relative to the air-gap spoken of, the tendency seems to be, to decrease it. A fifty k. w. machine now in the St. James Hotel is said to have an air-gap of but $\frac{1}{27}$ of an inch.

Mr. Adams:—I neglected to call attention to a criticism that was made with reference to the different densities in air-gaps of these two magnet frames. If you will notice what is said in the paper on the subject, you will find that the intention was to expend the same field ampere-turns in the air-gaps of each machine, so that we might expect the same change of brush lead. In other words, it is intended that the ratio of the field ampere-turns to the ampere-turns on the armature, which is, of course, going to determine the action of the machine as to change of brush lead and sparking, other things being equal, shall be the same in each machine. I do not know that there is anything necessary about any particular air-gap density. We have air-gaps in two machines here, and each air-gap requires the same number, very nearly, of ampere-turns expended in it to carry across it a certain amount of magnetism. One air-gap we have is comparatively short, $\frac{7}{8}''$ in all. The other is much longer, $1\frac{5}{16}''$. But the area of the short air-gap is so small as to make up in magnetic resistance the advantage it has over the other in the matter of length. The magnetic resistance of the air-gap in each of these two frames presented in the drawing is intended to be nearly the same. I do not know as I have said that there is intrinsically anything

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better about an air-gap density of 25 or 65,000 one way or the other. We want certain conditions in the air-gaps to control the operation of the machines, and if it had been thought or assumed what different conditions than those suggested here would control the action of the machines when delivering full load, they might have been assumed. They may still be assumed. We may assume, if you please, that we only want the field ampere-turns in air-gaps to be one and one-half times the ampere-turns of armatures, active at pole corners, and design frames to correspond to those conditions, but the same advantages will still hold in the use of wrought-iron.

[Adjourned.]

Discussion at Chicago, January 16th, 1895.

[Mr. S. Arthur Rhodes in the Chair.]

Mr. Edson:—Modern dynamos are usually built with wrought-iron field and a cast-iron pole piece, and especially is this construction prominent in incandescent dynamos. In the construction of alternators the iron requires to be very finely laminated for the field pieces, and it is also necessary to cast an iron frame around the laminated pole-pieces. In these two cases the entire use of wrought-iron would not, I believe, be particularly desirable, for the reason that it would be very difficult to make a 1000 H. P. generator in a sufficiently solid manner for carrying the magnetic lines around the circuit, while they can be cast free from blow-holes and made nearly perfect.

For some motors in particular, the cast-iron frame offers some advantages, in that it affords a more solid structure. With wrought-iron, the band would be too thin which would still maintain the proper magnetic conductivity in a good substantial manner, but at the same time we would have a machine, that with a forging of this kind, would be liable to spring.

Mr. B. J. Arnold:—I think that the points made by the speaker were well taken. It would be impracticable to make wrought-iron field pieces, and the cast-iron serves all the purposes. It is certainly much cheaper to construct, and the increased weight when put into the frame is nominal. From a practical standpoint it would be absolutely impossible to build wrought-iron frames for multipolar machines to put on the market in the present financial state of affairs.

Mr. L. L. Summers:—The diagram shows twelve inches to eight inches. I think that if the arms were to be of equal length, that the width would be different. I am more interested in the cast-steel part of the problem. I wonder if any one can give me any information on the cost of cast-steel. There seems to be a marked improvement in the last few years in the making of steel castings. There have been several attempts made in the west here to make steel castings, but I do not know with what success.

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I had occasion to use steel castings some time ago, and found that they were made in Buffalo. If cast-steel can be turned out at reasonable cost at all, it ought to be a very important advent in dynamo designing, because it would enable frames to be used which the engineer to-day is unable to use on account of the cost of construction.

MR. C. A. PRATT:—I think that the whole subject depends upon the size of a machine. In making small machines for motor purposes there is no question as to the advantage of cast-steel over cast-iron, especially as such machines must be small and light. On the other hand, in manufacturing large machines, there is an item comes in, which is not thought of in the smaller ones, and that is the amount of tool work. If wrought-iron forgings are to be used, there is much more tool work. Cast-steel is what is used, I believe, on street car motors. They are made here in the west, are perfectly satisfactory, and are made up to about 300 or 400 pounds without any difficulty, at a cost of about seven cents per pound. I think that the cast-steel is quite equal to wrought-iron.

MR. B. J. ARNOLD:—The question of tool work comes in largely in comparing cast-iron with cast-steel. The tool work on cast-steel is very much more expensive than cast-iron, especially if there is much planing to be done. It eats up tools and labor much quicker than cast-iron. The question in regard to machines is well taken. For smaller motors the wrought-iron frames are certainly the most efficient, but for larger work, I should say that cast-steel or cast-iron would be the best.

MR. PRATT:—There is a limit to this casting. It is not possible to make a casting larger than 400 or 500 lbs. A representative of the Westinghouse company guarantees to make me anything in cast-steel, and assures me that they can get most any kind of a casting that I want. As to whether they can do it, I do not know as I have not tried them. Five years ago in designing some heavy duty engines I used cast-steel for the cranks. We had some difficulty with the blowholes in those, but I have no difficulty since, and they tell me that they can furnish steel castings of any desired size. But these castings shrink considerably, and the pattern maker does not know how much to allow for this.

MR. ALBERT SCHEIBLE called attention to the author's diagram and said that so far as he could see the frames were made with a square cross-section. "I doubt," he said "if those proportions would hold good in larger machines of other types. As to the difference in cost of the tool work on wrought-iron and that on cast-iron, I should think this would be largely offset by the difference in the cost of copper in the armature windings."

MR. EDSON:—In connection with wrought-iron, I would say that it has one advantage, and that is, that a dynamo used on shipboard is a very small machine, and must get the greatest output from a pound of copper, or a pound of iron, and here

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wrought-iron would have an advantage over the other metals. But this would not apply in machines of larger type. In connection with steel castings, I would say that about 18 months ago I had some experience with steel castings, and found that they were full of blowholes. In the cores they were all right, but at the ends where we wanted them to hold firmly we discovered that just at this point they were very unsatisfactory. I have, however, seen some castings since, which were much better than these, and there has doubtless been considerable improvement in their manufacture.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 27th, 1895.

The 94th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order at 8 P. M. by President Houston.

THE PRESIDENT:—In the absence of Mr. Pope, our Secretary, who is unfortunately ill, Prof. Crocker has kindly offered to act as Secretary. The Secretary will please read the minutes of the last meeting.

Prof. Crocker read the minutes of the last meeting, and on motion they were adopted. He also read the following list of associate members elected and transferred at the council meeting in the afternoon.

Name.	Address.	Endorsed by
ANSON, FRANKLIN ROBERT	Manager, Salem Consolidated Street Railway Co., Salem, Ore.	F. L. Dame. P. S. Malcolm. W. C. Cheney.
CUMNER, ARTHUR B.	Senior Member, firm of Cumner, Craig & Co, 69 Broad Street, Boston, Mass.	S. S. Wheeler. F. B. Crocker. Geo. M. Phelps.
LECONTE, JOSEPH NISBET	Instructor in Electrical Engineering, State University, Berkeley, Cal.	C. L. Cory. F. F. Barbour. W. Meredith.
LOEWENHERZ, HERMANN	Mechanical Engineer, Met. Tel. and Tel. Co., 18 Cortlandt St, New York City; residence, 311 Hudson St., Hoboken, N. J.	Jos. Wetzler. Jno. J. Carty. T. C. Martin.
MACCULLOCH, ROBERT C.	Manager, Jos. Lough Electric Co., 503 Fifth Ave.; residence, 482 J. Lexington Ave., New York City.	H. W. Weller. G. Kirkegaard. R. W. Pope.
MAYER, MAXWELL M.	Manufacturer of Dynamos and Motors, 411 107th St., E. R.; residence, 242 E. 114th St., New York City.	A L. Riker. O. P. Loomis. Jos. Wetzler.
NYHAN, J. T.	Superintendent and Electrician, Macon and Indian Spring Electric Railway, Macon, Ga.	W. F. D. Crane. Edw. Caldwell. R. W. Pope.
PADDOCK, B. C., JR.	Assistant in Generating Dept., Edison Elec. Illuminating Co. of Boston; residence, Brookline, Mass.	F. A. Pattison. Henry Floy. F. W. Erickson.

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PRINCE, J. LLOYD	Engineer, 868 Flatbush Ave., Flatbush, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
REDMAN, GEO. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., Rochester, N. Y.	F. A. Scheffler T. C. Martin. H. A. Foster.
SWENSON, BERNARD VICTOR	Instructor in Electrical Engineering, University of Illinois, Champaign, Ill.	D. W. Shea. Sam'l Sheldon. Townsend Wolcott.

Total 11.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, December 17, 1894.

CROSBY, JAMES WELLINGTON	Electrical Engineer, Hix, Crosby & Co., New York City.
HIX, E. RANDOLPH	Firm of Hix, Crosby & Co., New York City.
BILLBERG, C. O. C.	Electrical Engineer, 3200 Arch St., Philadelphia, Pa.
CRAIG, JAMES HALLY	Firm of Cumner, Craig & Co., Boston, Mass.
SHAW, EDWIN C.	Manager, Akron General Electric Co., Akron, O.

Total 5.

Prof. Crocker also stated that the Council had decided to have the general meeting for this year held at Niagara Falls on Tuesday, June 18th, and had also changed a rule of the Council so that in the future ten gentlemen may be transferred from associate to full membership at any one meeting, instead of five. Heretofore the limit had been five, which necessitated keeping applicants on the list for a long time, and this change was thought necessary in view of the growth of the INSTITUTE.

THE PRESIDENT:—If there is no business which the INSTITUTE wishes to transact at this time, we will proceed to the paper of the evening, "Notes on Recent Electrical Engineering Development in France and England." It is not necessary to introduce to you Mr. H. Ward Leonard, who is so well known by all of us.

Mr. Leonard read the following paper.

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A paper presented at the Ninety-fourth Meeting of the American Institute of Electrical Engineers, New York, President Houston in the Chair, and Chicago, Mr. Carl K. MacFadden in the Chair, February 27th, 1895.

NOTES ON RECENT ELECTRICAL ENGINEERING DEVELOPMENTS IN FRANCE AND ENGLAND.

BY H. WARD LEONARD.

INTRODUCTION.

As a result of inspecting some of the most interesting of the developments in the field of electrical engineering during a recent trip to France and England, and as a result also of having met many of the engineers responsible for these recent developments, I find it difficult to reach a conclusion as to whether we, or our contemporaries across the water are ahead in the electrical engineering race.

Of course when one attempts to compare the electric developments of the respective countries commercially, we are in the same position as the "America" was in the historic yacht race, "there is no second;" but considering the recent electrical development from an engineering standpoint we are rapidly losing the lead we have thus far held.

Although I have always felt that so-called fundamental patents and the resulting enormous aggregations of capital and engineering talent under one management, were a millstone around the neck of our profession, I have never before had the opportunity of seeing positive and unmistakable evidence of it such as this visit abroad showed me.

In the beginning of electric lighting, both arc and incandescent, we led the world from an engineering standpoint, and were years ahead of any other country. But what has been done in this country in the way of a remarkable electrical engineering development since Edison started his first three-wire system at Sunbury, Pa., in July, 1883, and Westinghouse established his alter-

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nating system with 1,000-volt primary and 50-volt secondary a few years later, and Sprague started the Richmond electric road? A moment's thought will, I think, make you all realize that the practical development of electrical engineering improvements is almost impossible against the opposition of the gigantic corporations in that field, and that corporations having such a large portion of their capital represented by patents will not wish to see the practical trial of a promising improvement which they do not control, and which may depreciate the value of the methods they control or claim to control. It is in just this way that we are losing ground when compared with England and France.

We undoubtedly have the best three-wire central station plants in the world, also the best alternating system converting from 1,000 to 50 volts. But what other kind of central stations have we to point to? Practically none.

We have 500-volt continuous current electric railways galore, and we operate such railways at distances for which 2,000 volts should be used instead of 500, and after investing more money in copper per car than the entire cost of the electrical equipment, we still lose twice as much energy as is commercial in the line.

Is there a large electric railway system in this country which as an electrical transmission of power is a credit to our profession? Not one.

In France, and even more in England, one is forcibly impressed by the many kinds of central stations being tried. Many of them may seem almost sure to prove commercially unsuccessful, but who can say which one may not prove the "Sunbury" of an enormous electrical engineering development?

No capital or patents can prevent the slow development of evolution, but I fear that under the existing conditions we shall have to content ourselves with drawing pictures of what might be done, and watch the continued introduction of the three-wire system of 1883, the 1,000 to 50-volt alternating system of about 1887 and the continuous current 500-volt railway system of 1887, while our engineering friends abroad keep trying not only their own ideas, but the ideas of many of us from this side because they have the necessary encouragement and opportunity to do so, while we have not.

I have learned on this hurried trip abroad of many applications of inventions of American engineers which have proven very

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successful and which although patented, described and advertised in this country, were taken up first by English or French engineers notwithstanding their well known prejudice against American inventions.

Alternating Current Practice.

In England one of the first things which impresses an engineer is the total absence practically of a 50-volt secondary for alternating systems. It is the general practice in England of late to use a three-wire secondary with 100 volts on each side. I believe that every engineer who has ever given the subject a thought, knows that there was no excuse except patents for a 50-volt two-wire secondary originally, and no excuse except the inertia and prejudice of large corporations for continuing to put in the two-wire 50-volt secondary to-day.

Manufacturing and Engineering.

In England there is a multitude of medium size concerns, manufacturing electrical apparatus, and the competition is mainly on ideas, and not the cost of dynamos per kilowatt. It is surprising to find that generators and motors are much cheaper in the United States than in either England or France, notwithstanding their advantages over us as to cheaper raw materials and labor.

The manufacturers abroad generally consider the consulting electrical engineers as entirely unnecessary in view of the multiplicity of schemes which every plant brings forth from the various manufacturers, but I believe that a great deal of benefit has been and is being accomplished in England, by virtue of the custom of placing in the hands of good consulting electrical engineers the design, for instance, of a large central station plant to be built by a city itself.

Has a central station of this kind ever been built in this country? I think not; that is, a central station built according to advice from a good consulting engineer who was free to select the good features, and eliminate the bad features of the various systems known to the art. Imagine a central station combining apparatus and methods of the General Electric, Westinghouse, and Siemens and Halske all in one system, also taking advantage of other good ideas from the United States and abroad. Who can doubt that it would be better than could be built by using only the patents and apparatus controlled by some one company.

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Many will answer that all the best engineers are in the employ of the leading companies, and the consulting engineers available are incompetent commercially, and there is a great deal of force in this argument; but even if true, it certainly merely emphasizes the difficulty of getting a practical trial in this country of promising ideas in the electrical field unless they be controlled by one of the would-be-monopolists.

Rotary Transformers.

Rotary transformers are used in several stations in England for a continuous current high potential multiple arc distribution, the secondary being a three-wire system as usual. Such a plant is in use at Oxford. At Brighton and several other places the standard 220-volt continuous current three-wire system is supplemented for distant lighting and in newly occupied territory by the alternating system using about 2,000 volts in the primary, and a 220-volt three-wire secondary.

This alternating plant supplies the distant and scattered lighting during the period of heavy load, and during the period of light load (about three-quarters of the whole time) this distant lighting is supplied directly from the 220-volt three-wire system by switching the secondary circuit from the converter to the regular three-wire system.

Mr. Arthur J. Wright who installed this system first at Brighton, spoke of it to me as an American invention not patented in England, a description of which he had read in the American electrical journals, and was much surprised to learn that none of the central station companies had made use of it in the United States, as it was proving of the greatest value to him in his plant.

Steam Engines.

I believe we are ahead of England and France in the designing of dynamos and engines. Their workmanship leaves nothing to be desired, but giving consideration to amount of material used, efficiency and design, I think we are in advance of them.

One of the most surprising things to me was to see the almost universal use of engines which we would consider had practically no governor. That is, engines using slow acting throttling governors instead of the triumphs of engineering skill which are so common in this country. Not since 1883 have I seen such

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poor governors as I found generally used abroad in the finest and most recent stations, and upon engines which are almost perfection itself as regards manufacture.

The Parsons Steam Turbine.

The Parsons steam turbine was one of the most interesting things I saw in England. These steam turbines are direct coupled to dynamos, and in sizes of 350 K. W. revolve at 3,000 revolutions per minute, and of course run at higher speed in smaller sizes. The space occupied by a 350 K. W. outfit is over all about twenty-five feet long, five feet wide and including governor about seven feet high. These turbine plants when running at these high speeds are entirely free from vibration and are not even bolted down, but are supported by three pedestals, one near each end and one at the middle. There are some seven or eight bearings all in line, and a continuous stream of oil is forced through the bearings by a small pump driven by a worm on the main shaft.

The bearings used are extremely simple and very ingenious. The shaft runs in a gun-metal sleeve of about the usual dimensions, but between this sleeve and the surface of the pillow block are three cylinders of thin sheet brass concentric with the shaft, and sliding loosely over the gun-metal sleeve. The gun-metal sleeve is prevented from turning by a lug projecting down at one end into a hole in the pillow-block. The entire box being filled with oil, it will be seen that the shaft is free to vibrate slightly in every direction as it revolves, and that the viscosity of the oil tends to damp any such vibration. The three thin surrounding sleeves are perforated by a hole of about $\frac{1}{8}$ inch at about every two inches, so that the oil can work freely between these sleeves. The Parsons steam turbine uses the steam expansively as a reciprocating engine does. The steam at about 125 lbs., and preferably superheated, is led into the center of a cylindrical chamber in which the moving parts revolve. There are three of these chambers. In the first chamber the steam is expanded down partially, and thence goes to a second similar chamber and finally to a third one, which last chamber leads to the condenser. In each of these chambers the steam in its passage from the admission to the exhaust has to pass some thousands of small blades or teeth which project from the surface of the disks a fraction of an inch. The amount of steam used and its expansion, will de-

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pend upon the clearance, and the number of these turbine disks it has to pass in getting to its exhaust. It will be evident that the friction of the engine is less than that of a reciprocating engine, and that the condensation losses should be less. Also full advantage can be taken of high pressure and especially of superheated steam, for the difficulties of proper lubrication and packing in the presence of high temperature steam in a reciprocating engine do not apply to this engine.

Tests by Professors Ewing and Kennedy indicate that this turbine when in perfect condition has an efficiency of one K.W. hour in electrical energy produced by 28 lbs. of feed water, the turbine being operated condensing. This is equivalent to about 15.7 pounds of water per indicated horse-power per hour, and I understood that in a recent competition, a guarantee was made by Mr. Parsons which was equivalent to about 13 pounds per indicated horse-power per hour, and that his guarantee was lower than that of the best triple compound condensing engines of the reciprocating type which were in the competition. At Newcastle-on-Tyne I saw a central station of about 25,000 lights operated solely by these steam turbines, and which has been in operation since 1890 and has been earning and declaring dividends ever since it started. An interesting fact as to this Newcastle station is that all of the conductors are laid underground and consist of vulcanized rubber cables drawn into cast-iron pipes which are gas and water tight, and through which chemically dried air is forced from the station by a blower.

There are over six miles of piping and over 25 miles of cable, and after five years operation Mr. Parsons states that they have not had a single instance of failure of insulation, explosion or other trouble with the underground system.

The Laval Steam Turbine

Before leaving the subject of steam turbines, I will describe the Laval steam turbine of which I saw a number in the works of the manufacturers, Breguet & Co. of Paris. This steam turbine differs radically from the Parsons. The power is derived from the momentum of a jet of steam impinging upon buckets near the periphery of a disk, so that the machine is somewhat comparable to the Pelton water wheel. The steam, which is preferably used at a high pressure and exhausting into a vacuum, is expanded in a nozzle before reaching the disk, and reaches the buckets of

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the disk fully expanded, and hence moving at a very high velocity which the inventor claims is 3000 feet per second for steam at 85 lbs. per square inch, exhausting into the air, and 3700 feet exhausting into vacuum. The nozzle makes a very slight angle with the plane of the disk. The admission of steam is controlled by a centrifugal throttling governor. The number of revolutions of the disk per minute varies from about 30,000 to 15,000 in sizes from 5 to 50 horse power. The buckets are milled out of a solid disk of steel just inside of the periphery, so as to leave a solid band on the circumference. The edges of the buckets are quite sharp. The disk in the case of a 50-horse power turbine is about ½ in. thick. This disk is mounted on a small steel flexible shaft at a point about ⅓ from one end. At the high speeds in question, a body tends to revolve about an axis through the center of gravity, and since it is impracticable to make the center of gravity absolutely coincident with a straight line joining the bearings, Mr. Laval has used a flexible shaft so that the disk is free to assume such a position as to revolve practically around an axis, through the center of gravity, and consequently the disk revolves with perfect smoothness and without any trouble at the bearings at these enormous speeds.

No successful way has been perfected as yet for operating a dynamo directly at these speeds, and so Mr. Laval gears from his turbine shaft to two dynamo shafts, one on each side of the turbine shaft, by means of double helical gears beautifully cut, which reduce 10 to 1, and upon these two driven shafts are placed the dynamo armatures, two driven shafts being used so as to balance the side thrust on the bearing of the turbine shaft. The Laval people claim as high efficiency as that of any steam engine of the same horse-power, and there seems no good reason to doubt their ability to secure such an efficiency which they guarantee fully and specifically.

A careful test made at Stockholm in 1893, showed an efficiency of 20 pounds of water per horse-power hour with steam at 113 pounds initial pressure and used condensing. The weight of this turbine is about 30 pounds per horse-power in a size of about 30 horse-power.

The simplicity of this steam engine, also its theory and practical design in detail are most beautiful, and it seems likely to become an important factor in the electrical field. What is needed is a generator of electricity directly driven by, or preferably con-

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stituting a part of, the revolving disk, and here is food for considerable thonght.

Five-Wire System.

At Manchester I saw the five-wire plant designed by Dr. Hopkinson and recently installed. I inspected the central station for a few minutes only, as unfortunately those most familiar with the principal features of the system were absent at the time of my visit. The dynamos were bipolar machines driven from vertical engines by means of link belts with idlers. I cannot say that I was favorably impressed with the generating plans or distribution system, as far as I could judge of them in such a brief observation.

Liverpool Electric Railway.

At Liverpool I investigated the overhead electric railway. The overhead structure, the motors, methods of collecting the current, etc., were exceedingly well designed and constructed, and gave evidence of good working. The central station apparatus and design was not, however, up to the standard of work here in recent electric railways.

The series parallel control is used, but no rheostat, the designer seeming to realize that it might just as well be left out, and the equivalent resistance secured in the windings of the motors themselves, with less apparatus and no appreciable difference in economy or control.

English Central Stations.

In London I visited several central stations of which I will mention two. The first is that of the Metropolitan Electrical Supply Co. This company has an enormous area allotted to it. I will explain right here, that both in London and Paris the authorities follow the plan of granting to several different central station companies—supply companies as they term them—the exclusive right to a certain section of the city. No such company can run into any other company's section. At the central station of the Metropolitan company, I found four Parsons steam turbine units of 350 K.W. each, running at 3,000 revolutions per minute. These steam turbines had been in operation only a short time when I saw them, and had been installed for the reason that the central station had been enjoined by the courts from operating the reciprocating

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engines formerly in use because of the vibration they caused. I was informed that the vibration was particularly troublesome and difficult to overcome, because the central station was built upon made land, above the bed of a former river and that the ground was boggy and transmitted any vibration in the most surprising manner. I inquired as to the working of the steam turbines and was informed that they were not able to detect any difference in their coal consumption compared with the compound condensing reciprocating engines formerly in use. I found that an accident had happened to one of the steam turbines by which it had lost all of the blades in one of the three chambers, which reduced its capacity and efficiency considerably, but did not put it out of service entirely.

The other London central station I shall refer to, is that of the City of London Company. This company supplies the heart of London, that is the old "City of London," which is without doubt the best central station territory in the world, on account of the wealthy nature of the customers, the substantial character of the buildings, and especially because of the peculiarly dismal foggy weather in London. While I was there, artificial light was required almost as much by day as by night. This central station is beautifully located on the south bank of the Thames, near the center of lighting, and is a fine example of the best that can be done to-day with the alternating system under such conditions. I do not believe it would be possible to find less excuse for the use of the alternating system than in this station, and yet I expect it will pay, for it can hardly fail to earn money under such extraordinarily favorable conditions for lighting.

But I need hardly say that they have no motors except toys, and but few of them; and when I remember that in Chicago 40 per cent. of the connecting load is motors and that this percentage is rising all the time, it seems evident that the City of London Co., is terribly handicapped by the use of the alternating current. However, they have a 2,000-volt three-wire secondary, and operate the dynamos all on multiple-arc which is certainly using the alternating current to the best advantage. Aside from the use of the alternating current under these conditions, it is difficult to say anything in criticism of the central station.

The plant is arranged on the panel system, which Mr. Mordey says originated with him, and which is thoroughly carried out in this station, for each panel or section across the building com-

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prises an independent unit including a boiler, engine, dynamo, and switchboard for 500 K.W. The engines are vertical and direct-coupled to the Mordey alternators. The switchboards are entirely novel in design, being cast-iron pyramids about ten feet high, standing clear from the wall and having all of the conductors inside, with the instruments, etc., mounted on the front face. While very finely finished and ornamental, I could not but think that the vital parts would be more difficult to inspect and repair in case of emergency, than in our recent switchboard practice.

One detail of electrical construction in which the foreign practice seems very backward is the rheostats. In this magnificent station in the City of London, for instance, and in many other places I saw rheostats made by winding german silver wire on a slab of slate, which was then mounted on insulators horizontally on a table, and a slider arranged to move over the surface of the resistance wire itself, which was thoroughly exposed.

Another detail in which we are certainly in advance of foreign practice is our instrument work, for which we must thank Mr. Weston solely. I saw many fine instruments while abroad, but they seemed to be more suited for a physical laboratory than a central station, the substantial, compact, permanent features of the Weston instrument, with its readable scale and dead beat index were conspicuous to me by their absence.

French Central Stations.

In France the most interesting central station I saw was in Paris where I visited a sub-station designed for a capacity of 30,000 lights. The sub-station was supplied from a distant central station by means of a constant current of 250 amperes, all devices on this current being in series and the total E. M. F. running as high as 6,000 volts at times.

In the sub-station were rotary transformers, the primary ends of which were series wound motors and all being in series. The secondaries of these rotary transformers as generators, fed a five-wire system of conductors, and in multiple-arc with these generators across the five-wire system, was a bank of storage batteries. The lamps used were 110 volts; some of the rotary transformers had 110-volt secondaries, four of such secondaries being in series so as to make the five-wire system complete independently of the batteries. Other of the rotary transformers had 440-volt

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secondaries and fed the outside conductors only. On each rotary transformer was a rheostat which was in multiple with the series wound field and which by a step-by-step movement similar to that of the old U. S. automatic regulator, controlled the strength of the series field so as to keep the E. M. F. in the secondary, constant; the controlling magnet of the automatic being across the secondary of constant E. M. F.

The storage battery plant was well designed and seemed to be in good order. It was as clumsy and seemed as full of troublesome possibilities as those we have on this side of the water. It had capacity for 8.000 10 C. P. lamps for three hours and cost about $30,000, weighed about 400,000 pounds and occupied a space about 32 x 50 feet. This cost means about $107 per K.W. of output which seems a pretty high price to pay for a plant to generate electrical energy to-day, especially when it probably has an efficiency at three hours' discharge not above 60 per cent. Such a storage battery must be compared in cost with the cost of boilers, engines and dynamos per kilowatt, which would cost perhaps $50 per kilowatt, and whose efficiency would be 100 per cent. as compared with the 60 per cent. efficiency of the storage battery, since the storage battery must derive its energy from a steam plant first. The craze for storage batteries as the universal panacea for electrical troubles which we have all read so much about in connection with European practice, seems to be on the wane, if I may judge from the statements of the engineers, rather than the storage battery manufacturers, but when we remember that in France and England they do not know what a healthy motor load means, we need not be surprised at the claims of inefficiency for stations which do not use batteries, and hence run their boiler, engine, and dynamo for most of the 24 hours practically without load.

Importance of the Load Factor in Central Stations.

All central station people have known for years that the most profitable consumers were those who used their lamps for the greatest number of hours.

In other words, that the net profit due to a consumer was largely dependent upon the relation between his average load and his maximum load, which Mr. Crompton in England has aptly called the "load factor." Yet, while appreciating this fact, central station companies make their rates dependent upon the

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kilowatt hours used, and independent of the maximum kilowatts used.

Mr. Arthur Wright at Brighton in England, deserves the credit, as far as I know, for having first given commercial recognition to this load factor of the consumer. Mr. Wright supplies each consumer not only with a meter which registers the kilowatt hours used, but also a second meter of simple construction which registers the maximum kilowatts used at any time during the month, and the discount which the consumer gets is very largely due to the relation between his average and his maximum kilowatts.

Suppose that there are two customers connected to a central station and that the monthly readings show that each has used 900 kilowatt hours. By the usual practice in this country the bill would be the same, yet one bill may be due to the use of one and one-quarter kilowatts for 24 hours per day, and for 30 days per month, and the second bill may be due to the use of 30 kilowatts, an average of one hour per day for 30 days per month. That is, the first bill may be due to a steady load, such as a few lamps in a basement of a hotel or a ventilating fan, while the second bill may be due to a larger load of lamps used only occasionally, as in an office building or an electric elevator requiring 30 K.W. for a few seconds to start it up, and after starting requiring only 15 K.W.

With the same 900 K.W. hours per month for the two cases, the central station company should charge at least five times as much for the case having the elevator and small load factor, as in the other case.

It is a fact not generally appreciated that in any central station the cost of producing a kilowatt hour can be divided into two portions, one of which, such as interest on cost, depreciation, salaries, a small part of the labor and coal, vary with the kilowatt capacity of the plant, that is proportionately to the maximum load, and are independent of the number of kilowatt hours produced, and the other portion of the cost of producing 1 K.W. hour represented by the larger portion of the coal, labor, water, etc., is dependent upon the number of kilowatt hours produced, and is independent of the maximum load.

The fact about this matter which is least appreciated is, that the portion of the total cost of 1 K.W. hour produced, which depends upon the maximum load, is about two-thirds of the

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total cost, and the part dependent upon the output is only about one-third.

In a modern central station 1 K.W. of its capacity represents about $300 invested. Consider the two consumers cited above. Both loads are in use at the time of maximum daily load. For the elevator, the central station has to provide an investment of $9,000, for the ventilating fan, $375. Assuming interest, depreciation and similar charges, at 10 per cent. we have $900 to deduct from our gross earnings in the elevator case, before we reach net profits, and $37.50 in the other case.

Suppose we get 10 cents per kilowatt hour in each case, and that the cost of production independent of general expenses, interest depreciation, etc., is 50 per cent. of the gross receipts, etc.

This would mean that if we get 10 cents for each kilowatt hour in both cases, our gross revenue would be $90 per month in each case, and our gross profit $45.00 per month, or $540 per year in each case. But in the elevator case we have interest and depreciation charges of $900 a year, and hence have actually lost considerable money in supplying this customer, while in the other case we have made a net profit of over $500 per annum.

We would have to charge more than ten times the rate per kilowatt hour to the elevator, that we charge to the ventilating fan to make the same net profit on $1.00 of capital invested.

This load factor is a most vital question, and it is the difference in load factors in English and American central stations which makes storage batteries commercially possible there, and impossible here.

The average load factor of an English central station is less than 15 per cent., and even in London in December it is only 33 per cent., while in most American cities the load factor which averages 40 per cent. will in December in many cases be above 50 per cent.

This difference is due almost wholly to our motor load, which is an almost unknown quantity abroad. With a 15 per cent. load factor a storage battery may pay, but not with a load factor of 40 per cent., especially when the load factor in our central stations is rising each year.

If central station companies would offer such a discount due to load factor as to warrant an individual customer in installing at his own expense a storage plant which he would charge at the minimum rate per kilowatt hour by a steady current for twenty-four hours per day, and then used this stored energy to

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supply his periodical demands for an occasionally very large rate of energy, I believe it is possible that the central station companies, the storage battery companies and the consumers might all derive a profit from the arrangement. I have no doubt that a central station company could afford to make a rate of four cents per kilowatt hour for a continuous service night and day, and make a satisfactory profit, while it would surely lose money in supplying an elevator, such as described above, even at fifteen cents per kilowatt hour.

I believe that the following schedule of rates fairly represents the charges per kilowatt hour that should be made to customers of various load factors.

Load Factor.	Rate per KW. hour in cents.	Resultant gross income per annum per KW. of plant.
5	30	$131.40
10	20	175.20
15	16	210.24
20	13	227.76
25	11.2	245.28
30	10	262.80
35	9.2	281.07
40	8.5	297.84
50	7	306.60
60	6	315.36
70	5.3	325.00
80	4.8	336.38
90	4.4	346 89
100	4	350.40

It must be noticed that this argument would lose most of its force if the maximum load of the consumer did not occur at the time of day when the maximum load was upon the central station; but in elevators, and similar loads which call for their maximum load in starting up every few seconds, the maximum loads will not only occur together occasionally, but this will sometimes occur at the time of maximum load on the central station, and when this accumulated load is put upon the central station, the kilowatts must be there to meet the demand.

Electric Heating.

I saw evidences of a very healthy demand for electrically heated devices while abroad. In London the principal central station company is running at its own expense a show room for the education of the public in this line, and several manufacturers of electric heaters told me the demand was very satisfactory, and promised a good future.

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The Heilmann Locomotive.

In France I examined what I considered the most important electrical engineering development of all that I saw. It was the Heilmann electric locomotive. Having been for some years past a firm believer in the merit of this machine, and having been in correspondence with Mr. Brown, Mr. Heilmann's electrical engineer, as to an invention of mine used in this locomotive for the first time on a large scale, I was especially interested in it, and my hearers will please discount as they may think necessary my description of the advantages of a locomotive using my system of control.

The locomotive I saw was the first one built, and was not in service when I was there. It had run 2200 miles commercially, however, and as a result of the performance of this first locomotive which was 600 H. P., there are now building two locomotives of 1500 H. P. each, which it is expected will go into commercial service about June next.

This electric locomotive carries its own central station with it. It is really a complete central station on wheels, with its power used for propelling itself. Speaking from memory, I should say the length over all was about 50 feet. The locomotive is mounted upon two bogies each having four axles, so that the weight of the locomotive is borne by 16 wheels, each of which is about 45 inches in diameter. A platform made of heavy iron girders runs the whole length of the locomotive, and is supported upon two pivots one at the center of each bogie. Upon this platform is mounted the coal, water, boiler, engine, dynamo, etc., so that it will be noticed every pound of material is used upon the drivers and therefore becomes effective for tractive purposes.

The entire weight of the locomotive is 114 long tons; that is, about 15,500 pounds per driving wheel, which is about the same as our standard practice in this country. With a tractive coefficient of .2 this means a drawbar pull of 50,000 pounds and assuming friction at six pounds per ton, we find that 50,000 drawbar pull would enable us to pull 1900 tons on a one per cent. grade at a low speed, say 15 miles per hour, and would give us ample drawbar pull for handling a 200-ton train at any speed thus far seriously discussed.

Most engineers who have heard of the Heilmann locomotive have derisively dismissed it from their minds as a ridiculous monstrosity of a crazy Frenchman, but I have for some time

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believed, and am now convinced, that you will in the immediate future be bound to give this machine the most respectful consideration. I find that the impression prevails generally, that the modern steam locomotive is really a very perfect and efficient machine. This I think is far from being true. The efficiency of a boiler depends largely upon how perfect the combustion is, and with forced draft we can realize an efficiency of 80 per cent. with very perfectly designed boilers, provided we do not attempt to burn more than about 40 pounds of coal per square foot of grate surface per hour. But the maximum duty of boilers in locomotive practice such as for the highest speed service, involves the use of nearly 200 pounds of coal per square foot of grate surface, and I need hardly say that forcing the boiler in this way results in a terrible inefficiency. To produce an indicated horse-power in a steam locomotive at highest speeds to-day probably requires at least twice as much coal as is required in first-class stationary or marine boilers. This is the first place where Mr. Heilmann is able to show an economy; he is able to carry a larger boiler, and hence does not have to crowd it to such a wasteful point.

But regardless of an abundant supply of steam from the boiler we find ourselves greatly limited in power for steam locomotive practice at high speed, because of the wire-drawing of the steam, and difficulty of properly exhausting when we run our locomotive at its highest speed. The maximum drawbar pull obtainable when running at the highest speed, is only about half that obtainable at slow speed, no matter how much steam we have at command, or at what cut-off we work. Heilmann avoids this difficulty as we shall see presently.

Another matter of most serious importance is the tremendously destructive effect upon the roadbed and upon the locomotive itself, of the unbalanced vertical component of the motion of the counterbalance weight of the steam locomotive, and also the shouldering effect of the locomotive tending to spread the rails. Probably at least one-third of the cost of maintenance of the roadbed and the locomotive for high-speed service could be traced directly to this destructive "hammer blow" and side thrust. Both of these effects which become very troublesome as we go to the higher speeds, are entirely absent in the electric locomotive.

Having now pointed out the weaknesses of the steam locomotive which develop most forcibly as we increase in speed, I will

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describe the construction of the Heilmann locomotive and point out how those difficulties are obviated by the electric locomotive.

The steam engine is compound, well-balanced, and directly coupled on its shaft is the electric generator. A four-pole single reduction motor of the ironclad type is geared to each of the eight axles, and the motors which are series wound are in multiple with each other across the brushes of the generator armature. As the motor field must have a fair degree of saturation to prevent sparking when the locomotive is running light and pulling no train, it will be evident that under all operating conditions, the motor fields are constant, and fully saturated, which makes them entirely sparkless. The field of the generator is separately excited by means of a small auxiliary engine and constant potential dynamo, which also supplies the electric lights needed. The main engine has a fixed cut-off at the most economical point, say one-quarter stroke and its speed is adjusted by the throttle.

The engine in practice is varied in speed from perhaps 50 to 500 revolutions, and the strength of the generator field from zero to its maximum strength. It will be noticed that all the steam is used expansively at a fixed cut-off, and Mr. Heilmann lays great stress on this, although I myself would prefer an automatic engine running at a constant speed, and I believe that he would, if he could get as good ones abroad as we can in this country. For starting, an almost unlimited torque is secured by gradually increasing the generator field strength and speed, which sends a current through the motors, rising smoothly from zero to that current sufficient to start the motor armature. If we leave the field controller and throttle in this initial position, our train will start smoothly, and will continue to move slowly, using the full current, but producing the current with about 50 volts or one-tenth of the full voltage, and we will be producing this power, about one-tenth of that required at full speed, by a steam engine using steam expansively instead of, as in the steam locomotive, full stroke. But of course we desire to accelerate the train rapidly, so we keep on manipulating the field controller and throttle, until we finally have the engine driving the generator at full speed in a field of full strength, which will of course represent the full power of the locomotive. When we reach a grade requiring three times the torque required on the level, we weaken the field to one-third of its full strength. We will then move up the grade at about one-third

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of the speed on the level while using the same power as was required on the level.

It will be noticed that under the electrical arrangement on this locomotive, the electric energy is used in such a manner that its voltage is varied in proportion to the speed desired, and the amperes are in proportion to the torque required, so that the electrical energy produced is utilized in the most efficient manner possible.

Since this method of control of mine has been repeatedly criticized before this INSTITUTE on the score that a generator of such size and type when used as described would spark disastrously, I beg leave to say that I scrutinized most carefully the commutator of the generator which had supplied the current during the locomotive's 2200 miles service, and I never saw a commutator and brushes in more perfect condition, and the engineer assured me that under no circumstances had there been any sparking whatever. I regret that my method of control does not fit the generally accepted self-induction theory of sparking, but am forced to conclude that as something is evidently wrong, it must be the theory which fails to agree with the facts!

An electric locomotive of this kind would probably cost for the first few about $30,000, each being equipped with a 1500-horse-power boiler of our best marine type, and one of our best automatic cut-off compound engines directly coupled to a modern multipolar generator. I believe that a locomotive of this type could be built which would be able to pull 50 per cent. more weight than any of the present steam locomotives, and that it could pull the same weight at 50 per cent. higher speed. I think this type of electric locomotive is the stepping stone between the steam locomotive and the electric locomotive operated from a distant central station.

To properly try the experiment of operating a high speed locomotive of 1500-horse-power from a central station would undoubtedly cost nearly a million dollars. To try it with a locomotive of the Heilmann type would cost not more than $50,000 and if it proved successful, it is not much of a step to replace the boiler and constant speed steam engine with the moving contact and constant speed electric motor for driving the generator already tested and proven satisfactory.

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Discussion.

Mr. Townsend Wolcott:—I would like to ask Mr. Leonard if he can account for the difference in the efficiency of the Parsons and the Laval turbines. There seems to be, according to the figures given in the paper, a great deal of difference in favor of the Parsons. I was not aware that there was any such difference. In fact, I thought that if there was any difference, the Laval was rather the better so far as coal consumption per horse power was concerned.

Mr. Leonard:—I do not think there is any difference, and if there is a difference I am inclined to think, also, that it is in favor of the Laval. The tests made by Professors Kennedy and Ewing were upon larger sized units than the ones in the case of the Laval. I fancy that it may be that the smaller size was influential.

Another point which may perhaps be a little confusing is this: that the consumption of steam quoted for the Laval steam turbine of 20 pounds of water per horse power hour, is per horse power actually delivered, as you may say, in the generator armature. In other words, the friction of the bearing and the loss in the gearing is eliminated, and it is a horse power actually delivered, available in producing electric energy—of course, the efficiency of the armature is one thing left to consider—whereas the figures I quoted for indicated horse power are, of course, at the beginning, before any of the friction is eliminated.

Mr. John W. Lieb, Jr.:—The author of this interesting paper informs us in the first few lines that his observations were made during a trip through England and France. Later on we find that in making a comparison with central station practice in this country, he has drawn his conclusions so as to cover in his comparison not only England and France, but the whole world, and in this generalization he has, I think, fallen into an error which should not pass unobserved. While there are no doubt many excellent central stations in England and France, it is generally admitted, I believe, that the best types of both the low-tension three-wire and the alternating current systems of distribution, are not to be found in the countries visited by Mr. Leonard. The claims of preëminence for American stations of these types, which the author has advanced, can be shown to be not well founded if the comparison is extended, as it should be, so as to include other European countries where central station construction has been less hampered by local legislation. I would therefore call attention to several stations in European countries not visited by the author, which, had he found it possible to visit them, would have won his admiration and made his comparisons more just to European central station practice.

I would in the first place cite as types of the three-wire low-tension central stations which the author did not visit, the central stations at Berlin. The Berlin stations have a combined

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output inferior only to two or three stations in America. They supply with current a connected installation equivalent to about 95,000 amperes. The equipment of these stations—boilers, steam piping, engines, dynamos and electrical apparatus—would certainly not suffer by comparison with any of our best equipped and most recently constructed American stations. I am not in a position to quote any figures as to the economy of operation of the Berlin stations, having seen only one figure given as to the economy of generating. It is claimed that on the average throughout the year, 220 watts are delivered to the customers' premises per pound of coal, which is certainly an excellent economic performance. Although Mr. Leonard did not visit either the Düsseldorf or Hanover stations, both of these should have been included in such a comparison as he has made. In the case of the Hanover station, it is claimed that on an average during 1893, 220 watts were generated, and 180 watts delivered to the customer per pound of coal; Dusseldorf during the same period averaging 140 watts delivered per pound of coal. Neither of these stations would suffer by comparison with our best types of American low-tension stations. From the table compiled by the National Electric Light Association, including a number of American stations, it appears that the best 24 hours record covered by the table, gave 208 watts generated per pound of coal.

Coming to the alternate current stations which are included in the comparison, the author refers to conversion from 1,000 to 50 volts. As a matter of fact there are very few stations in England, France, or in Europe generally, transforming from 1,000 to 50 volts. The European standard for alternate current stations being 2,000 to 2,400 volts primary, transforming down to 100 to 110 volts secondary. Mr. Leonard has not included in his comparison with American statistics, the Vienna alternate current station, which would certainly not suffer by comparison with any station in the world. I must admit a limited familiarity with the alternate current stations in this country, owing to the fact that I have been abroad a number of years, but I think I am safe in saying that there is not an alternate current station in this country which in excellence of equipment, perfection of distribution, regularity of service, or economy in operation, is the equal of the Vienna station of the Internationale Elektricitäts Gesellschaft. Among the other European stations which ought certainly to be included in such comparisons as these, I would mention the alternate stations at Cologne and Rome. Both of these stations are excellent examples of alternating current station construction and contain characteristic types of modern equipment.

Passing along the paper I notice that the author calls attention to the system of charge to the consumer for current, used by Mr. Wright at Brighton. I would say at this time, that this system

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of charging on the basis of what the author happily calls the "load factor of the consumer" was first developed by Prof. G. Colombo, of Milan, Italy, the general manager of the Italian Edison Company, and it is still the basis of charge for current delivered from the Milan Edison stations. This system was first adopted in 1887 or 1888, and has been in use ever since with entire satisfaction to the consumer. I do not know that a definite claim for precedence in the application of sliding scale of charge has been put forward, but I take this opportunity to mention it. According to the system of charging for current in use at Milan, the consumer is at liberty to choose between two systems of payment; either on the basis: first, of a fixed charge of a certain sum, 30 francs ($5.75) per lamp installed per year, plus a charge of 3½ centimes (.67c.) per lamp hour as registered by the meter, or, second, a charge per lamp hour as registered by the meter on a sliding scale at a rate varying from a maximum of 7.7 centimes (1.5c.) per lamp hour, to a minimum rate of 4.8 centimes (.96c.), depending upon the number of lamp hours used per month per lamp equivalent installed. This system covers fully and satisfactorily the question of a consumer's load factor, and gives the best consumer—that is, the one giving the company the greatest return per lamp installed,—the benefit of the best basic rate.

Another interesting point referred to by the author of the paper is the question of the station load factor. In Mr. Crompton's inaugural address before the *Institution of Electrical Engineers* in London, he presented a curve showing the load on all of the London stations combined, on the day of greatest output of last year, December 19th. The load factor on this day was shown to be 33 per cent. It may interest the members of the INSTITUTE to know that the load factor of the combined stations of the Edison Electric Illuminating Company of New York on the day of last year when the output was greatest (December 10th) was 34½ per cent. The load factor of the lower district supplied by the company, in which is included a large motor load, is somewhat less than 34 per cent.; the load factor of the upper district, which has only a small motor load, being slightly greater. The total K. W. hours of output of the combined London stations on the date referred to was 96,240. The combined output of the Edison stations in New York City on December 10th was 60,633 K. W. hours. The maximum load carried at any one time was in the case of the combined London stations, 11,600 K. W.; combined Edison stations in New York, 7,354 K. W. The connected installation in the case of the combined Edison stations in New York was: incandescent lamps, 234,494; arc lamps, 3,014; motors, 7,616 H. P.; or a total equivalent installed of 178,000 amperes. It may seem strange that the load factor of such a district as the lower district of New York City, in which the motor capacity connected (in K. W. equivalents) represents 42 per cent. of the total connected installation, is not greater than in the case of the

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upper district, where the motor load represents only 16 per cent. of the installation. It should be remembered, however, that the lower district is eminently a business and industrial locality, and that after six o'clock the load curve drops off very rapidly to a minimum, while in the upper district we have a business and residential locality where the day load is light, but the evening load keeps up well and falls off gradually.

THE PRESIDENT:—In a paper so varied as this, and covering so many different fields, experts in which are present, unless a desire is expressed to the contrary I shall limit the speakers to ten minutes.

DR. CHAS. E. EMERY:—The author of the paper has in a racy and attractive way brought to the attention of those present, matters in which he has been interested and instructed abroad. For this pleasant duty, well performed, I am personally much obliged to Mr. Leonard.

Taking up my marginal notes in order; the paper on page 41 states that the Parsons steam turbine delivers one kilowatt for 28 pounds of feed water, and continues: "This is equivalent to "about 15.7 pounds of water per indicated horse-power per hour." The difference is so great it would seem that these figures need revision[1].

I have been interested in considering the possibilities of the Parsons and the Laval steam turbines. The high speed should permit the use of a small and comparatively cheap dynamo, and eventually the engines should not be as expensive as ordinary engines. Moreover, the very small space required is of importance in a large city. I have wondered why the turbines have not been introduced here. I made a special examination of the Laval steam turbine at the Columbian Exposition, and though I had a special invitation and wore a Judge's badge, I could not get the operator to put a load of more than three or four kilowatts on an engine rated at fifteen horse-power, the excuse being that there was water in the steam. The reported tests of this turbine are very satisfactory, but it is a question if it has yet been put in commercial form.

As to the question of the load factor, I think the critical point has not been referred to in the paper. It is a question more of the distribution of the load through the day than of the inequalities of local demands. It is considered unfortunate to take an elevator as an illustration, for, although it may take 15 to 20 kilowatts at times, and be shut off entirely for considerable intervals, the demand is distributed throughout the day and in apartment houses far into the night, and as it is very rare that the heavy

1. This may be explained by using rather low efficiencies. Twenty-eight pounds per kilowatt equals 20.89 pounds per E. H. P., of which 15.7 is practically .75, which is the joint efficiency of the engine and dynamo and corresponds approximately to 88 per cent. for the engine, and 90 per cent. for the dynamo, or *vice versa*.

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pull required by each of a large number of elevators will come at the same moment, by the well understood law of averages, such elevators make a fairly uniform load. It is very much like the average in railroad work. When a few cars are running the fluctuations are very great, but as the number is increased, the load, though still fluctuating, gives a large load factor during the time of operation. It seems to me that the use of elevators and of electric current for various household uses should be encouraged, because such uses are distributed through a large number of hours per day. The real cause of the low load factor is, that so many consumers want light at the same time. The evident cure, if practicable, would be to charge a higher price during the rush hours. The method which would best appeal to consumers, would be to reduce the price for current used during other than the rush hours. The Wright plan mentioned in the paper (p. 47) with a proper scale of prices, would possibly accomplish these purposes, but the results would probably be better understood by consumers if expressed somewhat as above.

The description of the Heilmann electric locomotive and its operation is certainly very interesting, and involves some important considerations. It is fair to say that I had not thought of this system respectfully until I read the paper. It did seem to be impossible, when there are steam engines and a steam boiler already on a locomotive, to install an electric plant in addition to a steam plant on a special car, and in that roundabout way make a locomotive which would in any respect be more efficient than the direct use of steam applied to driving wheels in the first place. A few facts and some very simple calculations show that the idea is not as ridiculous as it seems. It would be unreasonable to dispute the statement that the cost of the power from an ordinary locomotive is double that of stationary engines of the best type. There are two reasons for this; one, the necessity of obtaining such an enormous power from a locomotive boiler which with the customary construction must be put in a certain place under limited conditions, the effect of all of which is to bring the evaporation down to 5, or at most 7 pounds instead of 8 or 9. The other is the difficulty of obtaining economy with the simple arrangement of valve gear which has been adopted, and with such variable piston speeds as are necessary. If, therefore, the steam plant of the Heilmann locomotive can be operated for one-half the fuel or anywhere near that, this saving, not considering interest charges, will more than compensate for the losses incident to the generation and utilization of electric current, even if the 50 per cent. extra weight of the Heilmann locomotive be considered as to that extent reducing the weight of the train. The question immediately arises, however; why not adopt the distinguishing features of the Heilmann steam plant to a steam locomotive? It is perfectly possible to mount a boiler of larger size on a platform and to make locomotive

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steam cylinders which will operate as economically as those of an engine mounted on a platform itself, even if we have to increase the the size of the drivers to bring down the number of revolutions of the engine. Were this done, the locomotive would be as economical as the steam plant of the Heilmann locomotive and the intervening electric machinery would produce loss instead of gain. That is, when the progress that has been made in the construction of the Heilmann locomotive is analyzed along more general engineering lines, the improvement suggested is one in locomotives, and not specially in electric locomotives. Curiously enough the general features of the system have been already worked out for ordinary locomotives, but were so far ahead of the times that they have not been generally adopted. What was called the Fairlie locomotive, built some years ago, had two boilers mounted on a platform supported on two trucks containing only driving wheels. The steam was introduced to the cylinders through ball and socket joints. The system operated well, all the weight was on the drivers, and I think some of the original engines are still at work in one of the South American states. The Mason Locomotive Works took up the system later, using a single boiler, and with one propelling truck containing drivers at one end, and an ordinary truck at the other. This arrangement enabled short curves to be run on suburban routes, but Mr. Forney, now present with us, showed that this could be done with a locomotive of the ordinary type, carrying its own tender on the frame, but supported by a truck, as evidenced in the locomotives on the elevated railroads, and the Mason system has not been extended. The success of the Heilmann system will then only show the desirability of reviving the Fairlie system, perhaps using only a single boiler of large size.

At present, as Mr. Leonard suggests, it is well to encourage the development of the Heilmann system as a means of ascertaining the desirable details of a practical electrical locomotive, even if the steam machinery afterward be taken off, and the current supplied by some modification of the trolley system.

Mr. Herbert Lloyd:—The conclusions Mr. Leonard comes to, resulting from his inspection of a single battery plant in Paris, are, I think, a little unjust to accumulators. His figure of $107 per kilowatt for three hours' discharge, about conforms to the American practice, but the statement that a battery worked at this rate will not have an efficiency of over 60 per cent. is, I think, erroneous. All the large batteries installed in this country have been guaranteed at a much higher figure than 60; 75 is more common. In comparing the relative first cost of battery plant and direct power plant, Mr. Leonard gives a first cost for a direct plant of $50 per kilowatt of output as against $107 for a storage plant of the same output. I will quote the remarks of Mr. Edgar of Boston at the Cleveland Convention last week.

Mr. Edgar says:

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"A first-class steam plant costs $100 a horse-power; everything "inside of the building. That is being done to-day. The battery "costs us a little over $50 a horse-power to do the maximum "work."

One hundred dollars a horse-power for direct plant means of course $133 per kilowatt, as against $107 for battery, taking Mr. Leonard's figures. I have had occasion within the past thirty days to get an estimate on a direct electric power plant, and the figure of $100 per horse-power is the result of my efforts.

Were the comparison made by Mr. Leonard between the first cost of the two systems correct, his later remarks as to the profitable application of a battery with a 40 per cent. load factor, would have some weight, but with batteries costing less per kilowatt of output than a direct plant, that contention falls.

Next, as to the idea of installing small batteries in customers' houses, that is going back to the earliest methods adopted in exploiting storage batteries in this country. In Haverford, Pennsylvania, this was tried eight or nine years ago, on a large scale, but the idea of dividing a battery up into a lot of little installations, distributed broadcast, is vastly less practical than the installing of one large plant in the central station, and if it would pay the customer to install a small battery, it would certainly pay the lighting company to install a large one, as the first cost would be proportionately less, and the care and cost of maintenance infinitely smaller.

Mr. Leonard's remark that: "The consumers' maximum load "will sometimes occur at the time of maximum load in the cen-"tral station, and when this accumulated load is put upon the "central station the kilowatts must be there to meet the de-"mand:" is one of the best arguments I have ever heard in favor of accumulators.

Mr. A. E. Kennelly: I think we are much indebted to Mr. Leonard for his interesting paper. A subject of this kind is always interesting, because, while, proverbially, comparisons are sometimes odious, practically, they are also sometimes very pleasant, and by seeing what our neighbors are doing we can often gain some advantage for ourselves.

There are three points in this paper I would like to mention. The first is that mentioned on page 37, namely that this country has suffered by having the electrical industry in the control of large corporations, and then on page 39 Mr. Leonard goes on to state that dynamos and engines are better here than they are anywhere. I suppose Mr. Leonard would not say that lamps are worse here than they are anywhere else, or that motors are worse here than they are anywhere else. So that we are forced to the conclusion that the superiority abroad must lie in the system of distribution, because there is nothing left but the systems to account for it. I can scarcely imagine that it can be maintained that in the commercial application of distribution there is a superiority

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in European countries, because I think you have only to take up a map of England's electrical distribution systems for example, to see that the question of systems is a very rife one, and that there is no apparent uniformity of opinion as to which system is the best to employ, even under any given conditions. Thus it is stated by Mr. Leonard that under the most unfavorable conditions he can possibly imagine, an alternating system has been put in, in the middle of the city of London. He also mentions that dynamos cost much less here than abroad, and this in a country of corporate interference. Is that not an argument in favor of the fact that under the influence of aggregated capital, processes of manufacture may have been so perfected as to greatly reduce the cost of construction, and while no doubt the effect of large corporations is to limit and interfere in some directions with electrical applications, yet in this compensatory world the diminished price of electrical apparatus is an evidence of one beneficent effect of large corporations.

The second point is on page 46, where allusion is made to the cost of this storage battery as being capable of supplying 8,000 10 C. P. lamps for three hours, and costing about $30,000, meaning $107 per K. W. That is evidently based on an estimate of the coefficient in the lamps of 3½ watts per candle. I would like to ask whether that 8,000 lamps is not the true estimate, and that 4½ and even 5 watts per candle would not be a much more fair basis to take, in which the cost would come to $75 or $83 per kilowatt.

The third point I want to draw attention to, is one that Dr. Emery has already mentioned, and I think that it deserves all the insistence that can be brought upon it, namely that on pages 48 and 49, of this load factor. When you sell light to customers they all practically enter into a conspiracy to throw the light on at the same hour, just about dinner time, and you must have power in the station to supply it, but when you sell power to run intermittent 10 horse power motors, even though they each take 30 horse power at starting, by no possibility can the customers enter into any conspiracy to all start together, and all the figures based on such a conclusion with regard to electric elevator motors are greatly exaggerated in consequence, and the rates which should be charged for a kilowatt-hour based on elevator work are correspondingly exaggerated. As a matter of fact, I think it is well known that elevator load is objected to more on the score of the difficulty of maintaining regularity of pressure in the mains, than it is on account of the small load factor.

MR. WM. MAVER, JR.:—I should like to say that there is at least one electric light station in this country that transforms from 2,000 volts to 100 and to 50 volts; the converters being adjusted to either 100 or to 50 volts on the secondary. That is, I believe, the Manhattan Electric Light Company of this city. The change was made from 1,000 volts, transforming to 50 in

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the secondaries, over a year ago. Of course, however, they employ the two-wire system in the secondary. I should like to ask Mr. Leonard how the switching of the secondary circuit from the converter to the regular three-wire system in Brighton is performed. Others may be interested also in that. Also on page 41, whether the vulcanized rubber cables referred to are lead covered, or if not, in what way they are covered, if he knows; and also the manner in which the air is chemically dried before it is led into the ducts.

Mr. M. N. Forney:—There are some things contained in this paper in relation to the Heilmann locomotive which interest me very much. I might say in the beginning that I know very little about electricity, but I know perhaps something about locomotives. There are several statements in this paper which are urged in favor of the locomotive, and which perhaps could hardly go entirely to the credit of the electric locomotive. For example, it is said that the Heilmann locomotive rests upon sixteen wheels, and on page 51 that Mr. Heilmann "is able to carry a larger "boiler, and hence does not have to crowd it to such a wasteful "point." Now it is not quite clear to me why you are not able on an ordinary locomotive to carry as large a boiler on sixteen wheels as on an electric locomotive. An ordinary locomotive and tender is always carried on sixteen wheels although the weights are not exactly the same, the Heilmann locomotive being heavier. The electric locomotive must in addition to the engine and boiler and the other appliances, carry its electric machinery besides. So that it appears as though the old steam locomotive has something to say for its side.

There is another statement on the same page in which it is said "that probably at least one-third of the cost of maintenance of the "roadbed and the locomotives for high speed service could be "traced directly to this destructive hammer blow and side thrust." Now it would be interesting to know on what sort of evidence that statement is based. I confess that after being a student of railroad matters for a good while, I have never heard that so large a proportion of the repairs of roadbed can be assigned to any such cause as that. It is very true that experiments have been made showing that some very destructive action occurs in locomotives, in which there is an excessive amount of counterbalance. A good many cases have been quoted in which it is said that rails have been bent, and the experiments made at Purdue University also show that at very high speeds, with excessive counterbalance, the wheels raised up entirely clear of the rails. But it is also shown by the same experiments that there are substantially no injurious results when the locomotive is counterbalanced in a reasonable way.

On page 53, it is said that the cost of the Heilmann locomotive is $30,000. Now an ordinary passenger locomotive of the largest size can be obtained for about $10,000 to $12,000 at the

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present time. There would therefore be a difference of about $18,000 to $20,000 in favor of the present steam locomotive. I think hardly any prudent business man would venture to make an investment of that kind without allowing ten per cent. on the extra cost to cover the interest and cost of replacing it. That would give you an excess of interest account for the Heilmann locomotive of $1,800 to $2,000. You may take it as a rough statement that a locomotive will burn per year about $2,500 worth of coal. I am taking a rough average through the country. As you have $1,800 to $2,000 excess of interest for the Heilmann locomotive, you would have to do the same amount of work with $500 to $700 worth of coal with the Heilmann locomotive that we are now doing with $2,500 worth on the steam locomotive.

I am entirely ignorant of the appliances used on the Heilmann locomotive, and there may be features there which would give a very great advantage in locomotive practice. But from the showing that is presented here, it seems to me that there is a good deal still to be said in favor of the steam locomotive.

Dr. Cary T. Hutchinson:—It may be interesting to give some information about a large electric locomotive which has just been finished by the Baldwin Locomotive Works. This locomotive has eight drivers connected rigidly by side bars, making a wheel-base of 16 feet, the length over all being about 30 feet. The weight is 133,000 pounds uniformly distributed on the eight drivers, giving 16,700 pounds on each driver. There are four motors, one on each axle, the motors being built directly on the axle without springs of any kind between the armature and the axles.

The machine has a capacity, on a four hour test, of 1,000 horse power at a speed of 35 miles per hour. The regulation is the series parallel. The motor being: 1st, all in series; 2nd, two series by two in parallel; 3d, all four in parallel. There is also a resistance intended for use on first position in starting. The lowest speed, without resistance, is about seven miles per hour.

A test recently made at the Baldwin Locomotive Works showed an efficiency of more than 92 per cent. when operating 1,000 horse power.

The motors are designed so that they will work without sparking with full current in the armature at one-half normal field strength. That is to say, they will operate at any speed from 35 miles per hour up to about 65 miles per hour at the same power, the drawbar pull varying inversely as the speed. At speeds below 35 miles per hour the drawbar pull is constant, the power, therefore, being directly proportional to the speed.

The smoothness and absence of vibration was very noticeable in the test referred to. The entire machine was supported on four jacks, without bracings; when running with full torque, there was scarcely any shaking.

Mr. W. L. Bliss:—On page 51 Mr. Leonard says: "But regardless of an abundant supply of steam from the boiler, we

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"find ourselves greatly limited in power for steam locomotive "practice at high speed, because of the wire drawing of the "steam, and difficulty of properly exhausting when we run our "locomotive at its highest speed."

On page 52 he states further, "The engine in practice" (which I suppose is the engine which is driving the dynamo) "is "varied in speed from perhaps 50 to 500 revolutions, and the "strength of the generator field from zero to its maximum "strength." I have made a rough estimate here as to what that speed represented. In the first place, on page 51, Mr. Leonard complains that the high speed of the steam locomotive causes wiredrawing of, and difficulty in exhausting the steam, whereas these troubles are obviated in the Heilmann locomotive. He assumes, however, that in the Heilmann locomotive the prime mover runs up as high as 500 revolutions. I have made a little calculation on the margin. I remember that the Empire State locomotive No. 999 has 86-inch driving wheels. That would be a circumference of 22.2 feet. At 60 miles per hour the drivers would make 236 R. P. M., which is less than one-half as fast as the Heilmann locomotive would be going to make the same speed, on the assumption that the latter makes 60 miles per hour at 500 revolutions. If we go to 120 miles per hour (or 112 miles per hour, which is the record of the Empire State locomotive), we should not be running the same quite as fast as the Heilmann prime mover, so that I should think there would be no more difficulty with high piston speed and wire drawing in the Empire State than in the Heilmann locomotive, for the engines are evidently operating at nearly the same speed.

MR. RICHARD FLEMING:—In connection with the cost per kilowatt of the European dynamos, I would like to ask Mr. Leonard why the cost of the dynamos is higher there than here. Are they more liberally proportioned, or is the workmanship so much superior to ours that they have to charge more for them? Why is it? I would also like to state in connection with the use of the three-wire system on alternating lines, that in the winter of 1890-91 I built a small plant in the far west, in Washington, where I transformed from 1,000 volts in the primary to 208 volts in the secondary, using the Edison three-wire system. They were compelled to change from the regular continuous current three-wire system to the alternating, and used the same wire. We used the standard Thomson-Houston transformer with primary windings in multiple, and secondary windings in series.

MR. JOSEPH SACHS:—The remarks made by the previous speaker, bring to my mind a similar instance of a small plant installed in 1889, in this city in the Lenox Lyceum, which was wired to be operated by the Edison three-wire system. Afterwards a small alternating plant was installed at the station of the New York Steam Heating Co. adjacent, and two Westinghouse

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machines were put in, operated at 1,000 volts and the secondaries of the transformers operated at 50, were so employed as to operate all the three-wire Edison system in exactly the ordinary three-wire fashion. This was quite an original feature at the time, as not very much of this kind of work had been done at that date. I would also like to make a note of the line on page 42. "What is needed is a generator of electricity "directly driven by, or preferably constituting a part of the re-"volving disk, and here is food for considerable thought." I wish to say that several friends of mine at the present time are at work on such a device, and it has often seemed to me that it would be feasible to devise some form of unipolar or very simple commutating machine which could be coupled to the shaft of a very high speed turbine; and although the element of friction, which is really the principal thing to be overcome in a case of that kind is very severe, I believe that such a device can be operated. A self-contained dynamo and engine of that kind would certainly be the acme of simplicity and cheapness. Professor Crocker may perhaps be able to give us some figures in regard to the coupling of unipolar dynamos at these speeds to turbines.

Prof. Crocker:—I hardly think a subject of that magnitude can be considered a proper part of the discussion of a general paper of this kind. But I believe that some such device as you suggest can be made practicable. But it is such a large subject that it would require an evening for itself.

The President:—Before calling on Mr. Leonard to close the discussion I wish to voice what I am sure are the sentiments of the meeting, by saying how much we have enjoyed this able paper, and how the value of the paper is evidenced by the very general discussion it has called forth.

I would like to say on my own part that I do not share Mr. Leonard's fear as to the evil effects of gigantic corporations, although I do not desire to be regarded as speaking unqualifiedly in favor of them. I do not think, however, that the statement made, that the practical development of engineering improvements is opposed by the gigantic corporations in the electric field, is warranted by the facts. On the contrary, if I have read aright the history of progress of electrical engineering science in this country, it has not been in spite of the gigantic corporations, but by reason of such corporations that such progress has been made. If here and there an inventor does not succeed in getting his particular system adopted by a corporation, he may, perhaps, naturally feel that such corporation stands in the way of its introduction. But we should not lose sight of the fact that these corporations are in the field for business and will be apt to buy anything that has real commercial value. It might be true, if all the corporations were represented by a single body, that such gigantic monopoly might absolutely discard anything of value.

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But when we remember that there are several, perhaps, three or four or half-a-dozen, it is evident that a live company or corporation cannot fail to see the advantage of anything which possesses true merit.

I have shared the general surprise of probably some of you here in learning that the Heilmann locomotive, a locomotive that practically carries a central station with it, can show such favorable figures, as it appears to, regarding economy. It is a matter of great surprise to me, and I am rather disposed to think that a great deal of the supposed advantages possessed by the Heilmann locomotive, will in fact, be found to consist in an improvement on mechanical locomotive practice. If, however, it be true, what we have claimed for the great flexibility of electricity as a means of long distance transmission of power, will, it seems to me, to a very great extent be lost. It is a very interesting question, however, and I shall look to the solution of it with considerable interest. Of course, I recognize the question of speed as being in favor of the electric locomotive.

I will only say in conclusion, that as to Mr. Leonard's fear least all able consulting engineers should be controlled by these gigantic monopolies, that he affords a notable instance of an able one who I believe, has not yet been so controlled.

I will call now on Mr. Leonard to close this discussion.

Mr. Leonard:—I have so many points to answer that I hardly know where to begin. If I inadvertently embraced far more in the scope of my paper as regards the central stations abroad than I should have done, I regret it, and I can see upon reflection that there is cause for criticism if I have made remarks that are so sweeping as to involve stations which I did not see. In saying that undoubtedly we have the best three-wire central station plants in the world, I judged largely by my familiarity with those in this country by observation, and those abroad, which I have not seen, by published descriptions. But one point which I wish to mention is, that I do not consider that any conclusions can be arrived at in judging the matter by the question of how many watts are delivered to the customer per pound of coal. The coal in the cost of the central station energy is less than 10 per cent. of the cost. It may possibly be that such stations abroad may show better results than ours as judged by the statistics compiled by the National Electric Light Association. But I hardly think this would necessarily be a criterion either, because we all know the care with which statistics are prepared by foreigners and especially Germans, and we also most of us would be inclined to doubt whether all of the best of our United States stations had submitted full, detailed and accurate figures as to their production, to the committee that published the results in question. There are a great many points concerned in what I would consider the best three-wire plants, which are not at all covered nor rubbed out by the question of

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the watts produced per pound of coal, and among them are the question of the perfection of distribution of pressure, the question of kilowatt hours produced per annum, per dollar of capitalization; and especially the question of how much earnings the station is making per dollar of investment, in which latter two points I am quite confident, although I have not the figures to back up the statement, that we are ahead of the European practice. I was very much surprised to hear one of the speakers state that the load factor of the New York Edison central station was 34 per cent., and I am almost forced to conclude that we differ as to the definition of load factor, for I had occasion personally to secure unquestionable returns in 1890 from the central stations in Chicago, Brooklyn, New York, Philadelphia and Boston, and at that time those stations averaged about 40 per cent. for the load factor and the New York station was the best of the lot, and I can only explain any such falling off as is represented by the present load factor of 34 per cent. as due to the taking on of too many of these fluctuating loads like elevators. As regards the question of the load factor again, I happened to be with the president of the Chicago Edison company on my visit abroad, and while there he received complete statistics from Chicago in regard to the operation in December, and the load factor there during December was over 50 per cent. The speaker perhaps did not understand that my remarks were limited as regards the quotation as to the load factor in London to the month of December in which, of course, the load factor is higher than would be ordinarily the case.

Another speaker spoke of 28 pounds per kilowatt hour not being correct relative to 15.7 pounds per indicated horse-power hour. I think these figures will bear scrutiny, and I call attention to the fact that the first one was in feed water per kilowatt hour in useful electric energy and not horse-power hour, and the second is per indicated horse-power hour.

As to the argument which has been presented by more than one, that while the Heilmann locomotive has a larger boiler that there is no reason why similarly a steam locomotive should not have a larger boiler, I beg to say that while I do not profess to have any very great amount of knowledge on that subject, I have given some considerable attention to it of late, and have noticed the comments and the writings of a good many persons who claim to be very well versed and apparently are, judging by their papers and by their standing, and the impression that I have derived is that there has been reached, very closely, a limit in the size of the steam locomotive boilers; that to make and place a larger boiler upon a locomotive to-day leads to such difficulties in many other ways as to be practically prohibitive, and I can only wonder if they can run with a steam boiler sufficiently large, why they burn twice as much coal as we do with stationary boilers. There seems to be no question that they do burn more

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coal to produce a horse-power, and that it is due to the fact that they do have too small a boiler and crowd it too hard. If they can, why don't they put on a bigger boiler?

As to the cost of batteries, engines, etc., relative to each other, the figure of $107 per kilowatt I think is quite close to the mark of present practice, and I will say that in discussing this question with one of the best posted men in England, after considerable argument and figuring on his part, he stated that the cost of batteries, such as they made, would be $175 per kilowatt. As to the cost of engines, boilers and generators, I am satisfied that if any such figure as $100 per horse-power has been quoted, that it must have been intended not to cover the boiler, engine and dynamo merely, but possibly the value of the real estate and buildings, etc., which they represent also, and which I have not included in my figures, as there is no doubt but that large boilers, engines and dynamos can be procured not only at $50, but I believe at considerably less per kilowatt.

A criticism was made as to the suggestion of placing the batteries upon the consumer's premises instead of in the station. I think the speaker has lost sight of the fact that the only argument in favor of placing the battery in the position which I suggested, was to enable the customer to obviate the necessity of calling upon the central station for these large spurts of energy which he required with its consequent high cost due to small load factor at the rates I named. Placing the batteries in the central station would not correct the disturbance of lights or the drop in the conductors affecting other consumers, nor could the station afford to give to the customer such a low rate when these variations in the customer's load are still in existence, as he could if it was a constant current supplied to that customer for twenty-four hours per day. I must say that knowing the general views of American central station managers about storage batteries, I thought it would be rather in consonance with their ideas if they could get a customer to buy the batteries and maintain them.

As to the $300 per kilowatt, that $300 per kilowatt represents not of course, merely the boilers, engines and dynamos, but it represents the underground system which is very expensive per kilowatt, also the real estate and buildings, and possibly the usual percentage for the franchise, patents, etc.

I had no intention of impressing my hearers with the idea that the European practice was ahead of ours at the present moment. In fact, my opening clause stated that I was in doubt as regards the matter. But I did point out that they were making more progress than we were in this country in trying new methods, new apparatus and new combinations, diverging from the old beaten paths, and I consider that practice due to the fact that there are so many concerns over there which are considered first-class and are almost always in any competition which arises. In this country when a large central station plant is to be installed,

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as we all know, it is not competed for by 25 or 30 concerns, the majority of whom are engineers who undertake the entire construction of the work and manufacture the apparatus in addition; but generally the plants are built by the people themselves, by some one of their employes, merely purchasing the apparatus from some one or two or three manufacturing concerns.

As to the question of dynamos and motors and the argument that we have, as I thought, better dynamos and motors than they have abroad, I can only say that I think the best reason for this is that there are no patents on them which even the smallest concerns are afraid of, and therefore we do have active competition from the smaller concerns, which do not have large capitalization due to patents and heavy fixed charges, which necessitate the large profits of corporations such as I was commenting on.

The point as to the batteries not having been properly estimated by the fact that three and one-tenth watts was assumed, is not correct. The lamps were assumed at three and one-half watts per candle. Even if for the sake of argument it be assumed that the battery will cost $80 or $90 per kilowatt as against $50 for engine and boilers and dynamos, it would not affect the conclusion materially.

The argument was advanced that we ought not to consider the elevator as being a kind of load that was detrimental in its present state, because it is running all day long. But that does not alter the fact that if it does run all day long it only has a load factor of five per cent., and the revenue of that per kilowatt is only $131 per year, even at 30 cents per kilowatt hour, and that it will come on and be on the top of the peak of your maximum load. As an instance of that, I have a practical figure of an elevator which does require about 30 kilowatts to start it up, and its bill is $75 per month and it does come on the top of the peaks at the maximum load.

As to the plant in Brighton and the question of how they do the switching, I will say that in that instance the different sections I referred to are somewhat like the spokes of a wheel and there are only about four or five such switching points, and they do, in that instance, thus far control them by hand. That is, the operator goes and throws the switch and then goes to another point. But methods have been devised by which they can be handled from the central station automatically, and if there were any sufficient reason for it at Brighton it would have been done there, as they were fully aware of the method and its feasibility.

As to the underground system at Newcastle, the conductors are not lead covered, as I remember the matter, but are covered, I think, with jute or some similar material, and the air is chemically dried by being passed, I think, over chloride of lime.

As to why the cost of small dynamos and motors is higher in European practice than here I do not know; but I am inclined to think that one of the reasons is that in this country the

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present popular method is for the manufacturers to bid on the machine delivered f. o. b. without any further work done in connection with it, and consequently there is very little chance for argument one over another, if the machines are very good and the competition is very keen. Whereas the method abroad is for the man who builds it to install it. In other words, the men who are manufacturers are generally electrical engineers, and they build and wish to install their own machines and consequently do not care to bid so low on the dynamo alone.

One of the speakers mentioned that there was no reason why there should be any more difficulty in the ordinary locomotive in taking care of the steam and using it economically in the cylinder and delivering it rapidly and exhausting it properly than there would be with the Heilmann locomotive. But I call attention to the fact while, of course, it is theoretically conceivable, that we should have a type of valves independently controlling the admission and exhaust in the ordinary locomotive, such as we have on stationary engines, we do not have them. It has been tried and retried and they have stuck to the simpler type of Stephenson link and slide valve, because the additional economies obtained by the use of the higher class of valve motion did not compensate for the additional complications introduced, which, however, does not apply at all to a steam engine placed above on a platform in which the most refined mechanism can be used to the best advantage.

I would like to call attention to one thing that I do not think I mentioned in the paper, and that is that by actual test by the engineer of the Chemin de fer de l'Ouest, who conducted the test of the Heilmann locomotive, they did operate the Heilmann locomotive over exactly the same distance, the same roadbed, running on the same time, hauling the same weight, the conditions being identical in every particular, and the amount of coal used by the Heilmann was 24 per cent. less than the amount used by their best compound locomotive. A point which was made by one of the speakers was that there was no reason why if we used 16 wheels on a steam locomotive we should not be able to do just as well as the Heilmann does with its 16 wheels. It seems to me that it would be difficult to conceive a steam locomotive with 16 driving wheels. It would meet with difficulties upon the curves, and the rigidity of the steam locomotive is certainly going to be troublesome if we come to make a machine 50 feet long, all upon the drivers, and I wish to emphasize the point that every pound of the weight of the Heilmann locomotive is resting on springs, and there is no rigidity of the wheel base. There is the four-axle bogie at one end which has a flexible arrangement connecting it to the platform above, and a similar bogie at the other end, and there is no such difficulty as regards rigidity of construction as it seems to me would be met with in the steam locomotive under the same conditions.

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And, furthermore, it impressed me that there is not an exact parallel, for the reason that a part of the 16 wheels counted as belonging to the steam locomotive by the speaker are on the tender and they are not at all effective for traction.

As regards the question of wear, and the statement that one-third of the cost of maintenance of roadbed and locomotive is represented by the destructive effects of the hammer blow and side thrust, I certainly would not dare to make any such figures as that for myself. I got that figure from a discussion which was held recently before the Civil Engineers' society and the figure was one which seemed to be agreed upon by more than one speaker. The speaker who named that figure, I think, was Mr. Strong. At any rate it was one whose name was familiar to me as that of a man who has had a very wide experience and is a pretty good judge of such matters and whose statement ought to be rather authoritative.

Another point I wish to bring out is this—they made measurements of deflection in crossing bridges in the case of the Heilmann locomotive and in the case of the compound reciprocating steam locomotive, and the deflection measurement showed that the deflection in the case of the steam locomotive was 80 per cent. more for the same weight than in the case of the Heilmann, which of course is attributable to this hammer blow effect, and which one of the speakers has pointed out has been found, in the case of a little error in the counterbalancing, to be sufficient to entirely lift the weight of the locomotive from the rails at times, as evidenced by tests at Purdue.

I agree with one of the speakers who said that he thought that our progress was not in spite of, but by reason of the big corporations; because I think that such progress in the engineering line, as we have been lately making, has necessarily been made by these corporations, because they have blocked other people who were trying to go ahead.

The same speaker mentioned the misfortune of losing the flexibility which we had all been attributing to the electric locomotive as compared to others, and that in the Heilmann that flexibility seemed to be lost. It seems to me it would be difficult to find a finer example of the flexibility of electrical transmission of power than is illustrated in the Heilmann locomotive. We can have an engine running at constant speed in one direction, and from that we can get any possible reduction or any torque we desire and any speed in either direction, and the flexibility is as perfect as is conceivable to my mind. In fact, it seems as though the electric energy were used there as a flexible connecting rod acting through an infinite number of gears, and between the source of power and the work that was to be done.

Another point which has occurred to me is that conceiving that we could put bigger boilers upon our locomotives, bigger

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drivers and cylinders, until we finally could secure the horse-power necessary to handle the high speed or large loads, one difficulty which I have recently noted about an engine of that kind is that it cannot start. It may run at full speed when it is in motion all right, but even with the drivers we have to-day and with the boilers, etc., it is impossible for the Empire State express to start itself at Albany, and it is necessary that a freight locomotive, a slow speed locomotive with eight or ten drivers should come along at the other end of the train and push it before it can start. No such difficulty as that pertains to the Heilmann locomotive or any similar locomotive, because there is an unlimited torque for starting, and I point out that the two limitations in present practice for locomotives are it seems to me, that we want to go faster, that is one point and as to that, we have every advantage in connection with the electric locomotive; and the other point is, we want to pull more freight cars up a grade, and we can do that better with an electric locomotive than to my mind we can ever hope to do with a steam locomotive.

Communication Received After Adjournment.

Mr. Lloyd:—[*Communicated.*] Referring to Mr. Leonard's reply to the foregoing criticisms, (to which I had no opportunity of replying at the time,) I can only say that if Mr. Leonard denies that a first-class generating plant costs $100 per horse-power, he is mistaken. The remainder of his reply is simply facetious, and not logical or consistent. The experience of engineers in this country with batteries ten years ago has no bearing on the results obtained to-day. Apropos of this, if my information is correct, the express object of Mr. Leonard's visit to Europe was to investigate steam turbines, of which he speaks so glowingly, with the idea of adopting them for driving the generators used in the welding of street rails. Immediately on Mr. Leonard's return he contracted for the use of three complete battery installations to do this work instead of the steam turbines.

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Discussion in Chicago.

The Western members of the Institute held a meeting in Armour Institute on Wednesday evening, February 27th, the same evening as the New York meeting. Mr. B. J. Arnold, the Local Honorary Secretary, called the meeting to order, about forty-five members and visitors being in attendance. Upon motion, Mr. C. K. McFadden was appointed Chairman. The paper of the evening, "Notes on Recent Electrical Engineering Development in France and England," by Mr. H. Ward Leonard, was read in detail by Mr. A. V. Abbott, after which it was discussed at length as follows:—

Mr. B. J. Arnold:—One point made by the paper is with reference to the adoption of higher secondary voltages abroad. This is something which we are bound to come to in this country, and a large number of station managers are even now adopting 100 volts on secondaries. For my part, I can see no reason why it should not be done, but I think that the cause of its not being looked upon favorably in the past, is that people were unable to obtain suitable lamps.

On the Subject of the Steam Turbine.—I was very much interested in the Laval steam turbine at the World's Fair. I was in its vicinity quite often, and I must say that the economy realized by these engines is something remarkable, when we consider that they are rotary engines in reality. They do, however, utilize the force of steam quite expansively to an extent which few other rotary engines do. I understand that one of the difficulties encountered when running at this enormously high speed is to cause the disk to thin out near the shaft or expand from the shaft, rendering it useless. There is only one remedy for this, and that is to run slower, which, of course, will reduce the efficiency. At a speed of about 30,000 revolutions per minute. the metal begins to expand, the rim gets larger and larger, and when the wheel stops, it is of greater diameter than when it first started.

On the Subject of Batteries.—From the records I have of European stations, I find that the average commercial efficiency is about 76 per cent. (The author gives 60 per cent.) His statement is high enough at the high rate of discharge which he gives, but batteries should be, and usually are, operated at a lower rate of discharge. When operated properly at a discharge of 10 per cent. of their capacity. the average commercial efficiency is about 76 per cent. The highest may run up to 78 per cent., and the lowest to 73 per cent. The greatest difficulty that we have in this country with batteries arises from two causes; the first is in the commercial desire to place something on the market for as little money as possible. The result is that there have been a number of plants installed throughout the United States, which have been too small for the work required of them. The batteries were unable to stand up under the work and went to pieces

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in a short time. Another side of the same reason is, that the batteries have not had sufficient lead in them to do the work; therefore, their life was very short. Battery plants have been installed in this country under conditions where they never should have been, with the exception of saving something, viz.: in cases where the work has been too great, and where engines and dynamos should have been installed instead. Where the average load throughout the twenty-four hours is large, it is useless to install batteries, except as regulators for railway stations, where they will show economy; but where the load is at its maximum for a few hours each day, as it is in apartment houses, and light for the larger part of the time, they will show a decided gain in operating expenses, if properly installed and operated, as the entire labor is eliminated from the plant for over half the time.

Some months ago, when the Heilmann locomotive made its appearance, I expressed a very decided opinion against the general plan of the machine and what was claimed for it. I have watched its record as closely as possible from the technical press, and fail as yet to see good reasons for changing my views regarding it. The only possible advantages it seems to me to have, are the ability of applying a continuous rotating effect or torque to the drivers, and the abolition of counterbalancing, which is destructive on roadbed and track. It has all the disadvantages of the ordinary locomotive, so far as cleanliness is concerned, and is still further handicapped by its excessive cost and extra expense for men in operating it. I think its chief function will be as an entering wedge for the adoption of electric traction on steam roads, or rather as a go-between between the steam locomotive and the electric motor driven from a central station.

Prof. W. M. Stine:—The paper covers so much ground that one is almost at a loss to attempt a discussion of it There are a good many things that can be said with reference to what the author calls the storage battery issue. I quite agree with the remarks made by Mr. Arnold. I have seen figures given in the London *Electrician* within the last month, giving energy efficiency, not ampere efficiency. In Europe, where they seem to be making most use of the storage battery at present, the conditions under which it is operated are very different from this country, and on this basis alone it is questionable whether we would be justified in imitating foreign practice. It can perhaps be shown that a storage battery plant, when well taken care of, will prove satisfactory and economical. This subject was pretty thoroughly discussed at the Cleveland meeting last week, and there were some very surprising figures given. I think, however, that the average central station manager in this country is not very enthusiastic over the storage battery.

Analyzing the weight of a locomotive, we may divide it into three factors. The one factor is that of the supply weight, and the weight of the tender itself. The next factor is the dead

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weight on the pony wheels, and the third factor is the tractive weight on the driving wheels. If we average the tractive weight of the ordinary express locomotive, the dead weight reaches the large value of 40%. We may accept this as the real condition of affairs, but the 40% dead weight is what to a great extent is causing the present railway financial condition. Much of the increase in the cost of construction and maintenance of the railways seems to be necessitated by the useless weight carried by the engine. It is not the train so much as it is the dead weight of the locomotive which is responsible for these things. If electricity is ever going to accomplish anything at all it must be in lessening this 40% dead weight. The question of the Heilmann locomotive is whether it can be reduced to the necessary tractive weight. I think that the total tractive weight is not excessive for the speed the locomotive can attain. This question was raised the other day by a railroad man, and for this reason I have made an analysis of the Heilmann locomotive.

MR. C. K. MACFADDEN:—That part of the paper referring to the Heilmann locomotive was the most interesting section to me. I have made a number of tests on passenger locomotives on one of our largest western roads, and I was prepared to find some very peculiar results when I started in on that work. My experience I must confess was very surprising, when in taking my first indicator cards from a modern ten-wheel engine, I found them to very closely resemble cards taken from an automatic high-speed electric light engine, whose valves were in first-class condition. The boiler had about 1,400 square feet of heating surface, and I have taken cards from the engine it supplied up to 1,000 H. P. This locomotive was one on which it was impossible to make the wheels slip, even with a full boiler pressure, which varied from 160 to 170 pounds. The speeds ran as high as 70 miles per hour and over, and all tests made were on locomotives running in the regular fast passenger service. The engine was a new one weighing 90 tons, and the total weight of train was 450 tons. I have here a few cards taken in this test. The first card shows the action of the valve motion when the point of cut-off is being altered. The second shows the steam distribution when the engine is developing 540 H. P. at 26 miles per hour; the third card shows the engine running at a high speed, 66 miles per hour, developing 904 H. P.; the fourth shows it running at 42 miles per hour, 641 H. P., and the fifth shows it at 36 miles per hour, 720 H. P.

I will say that I quite agree with Mr. Arnold in regard to the Heilmann locomotive. I can hardly see where the immense economy can be attained by using such a system. The first thing to be considered is the original cost. The cost is given as $30,000, and, though this is but a single locomotive, the chances are that it would cost $25,000 in lots of ten. A locomotive can be bought for $8,500 to $8,700, of the size spoken of, on which tests were

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made by me. It will develop 600 H. P. continously. The wages of a competent road engineer are undoubtedly much higher than that of a stationary engineer, and the wages of the help required on the Heilmann locomotive would certainly be even greater than on a common locomotive. Of course we know that it is useless to expect the steam railroad to incur the enormous expense necessary to give electric traction a trial, unless there is no doubt of its making a large saving over steam. When the Heilmann locomotive is given a thorough trial, the test of electrical traction will have been at an expense of only $30,000. I think the electric locomotive has much to commend it for high speed service, but I do not think that it will come into common use in the form shown in the French engine. I think that as a motor at the front of a train it will have its greatest value. There is no doubt that a train can be pulled by an electric locomotive. This is certainly possible, but this is not the question. The question is whether or not a railway president can say to his stockholders: "I can make a net saving in operating expenses by adopting electric locomotives over the best I can do with steam."

MR. SUMMERS:—What about the back pressure?

MR. MACFADDEN:—I made a number of tests on this subject, and found that the back pressure varied largely with the engineer, although, of course, the exhaust nozzles retard the steam to some extent. Intelligent work on exhaust nozzles has greatly reduced back pressure, and the back pressure shown on a few cards will explain my meaning, all of the figures being taken from the same engine the same day:

560 H. P.,	18 miles per hour.	Maximum back pressure,	28 lbs.
900 "	66 "	"	"	"	15 "
720 "	36 "	"	"	"	13 "

I tried letting the lever down to the last notch when running at 30 miles per hour, and found that the back pressure ran up to 56 lbs. The thermal storage in a locomotive boiler comes into play in a very remarkable way. A boiler can supply for a limited time 1,000 or 1,100 H. P., but will not supply more than 600 H. P. continuously. I found that in hauling this particular train, which was a very fast one, the amount of fuel used was very reasonable. A ton of cheap coal will carry a train of this kind 28 miles, the locomotive making possibly 4,500 miles in a month, which is twice the distance traveled by the Heilmann locomotive as yet. A pound of coal is equivalent to 5.1 ton miles. On another series of tests which we made, we found that we averaged for a week 8.2 lbs. of water per pound of coal. This coal was a good grade of Pittsburg coal. The average on some 1,000 different locomotives was found to be from 5 to 6 lbs of water per pound of coal, the fuel being cheap Illinois bituminous coal. As I say, this engine was handled in a proper way. The valves were balanced, so that it was a comparatively easy matter to manage the valve motion. I simply give this as an example of such

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an engine, as it is used to a great extent on a number of our largest roads.

I would say in conclusion, that the average locomotive is hardly a fit standard from which to judge the saving to be effected by the use of electricity. There is often a great difference in different engineers, sometimes 30 per cent. being the saving effected by one engineer over another on the same train and engine. Three months' work among the engineers of a prominent Western railroad by its superintendent of motive power has already effected a saving which will pay 6 per cent. interest on nearly two millions of dollars, and he thinks his work has hardly commenced.

Mr. A. V. Abbott:—I was called upon, some years ago, to design a plant for electric lighting, in which the circuit spread over a considerable territory. The station was operated by water power, the cost per annum being $5 per H. P., so that the expense of the power was comparatively small. The town was laid out in a series of blocks extending in three parallel lines away from the station. The design of the plant involved operating at 3,000 volts alternating, running a series of feeders from the station. The center of distribution was located as nearly as possible at the electrical center of gravity of the leading section of the town. The transformers, instead of being placed in each house, were arranged on the diagonally opposite corners of each block, and the secondary mains were arranged upon the three-wire system. By this means, with the use of a comparatively small amount of power in the secondaries, the transformer load was steadied to a great extent, a notable saving in the number of transformers and connections being accomplished; and the experiments showed that the transformers were operated at about 80 per cent. of their calculated load.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 20, 1895.

The 95th meeting of the INSTITUTE was held this date at 12 West Thirty-first Street, and was called to order by President Houston, at 8.05 P.M. Eight-five members and guests were present.

The minutes of the meeting of February 27th were read by the Secretary and approved.

THE SECRETARY :—The following are the names of Associate Members elected, and transferred to full membership at the Council meeting, held March 20.

Name.	Address.	Endorsed by
BOYLES, THOMAS D.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	C. P. Steinmetz. H. M. Hobart. H. G. Reist.
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Thorburn Reid. C. P. Steinmetz. H. M. Hobart.
DUNCAN, JOHN D. E.	81 Maplewood Avenue. Pittsfield, Mass.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
ESTY, WILLIAM	Instructor in Electrical Engineering, State University, Champaign, Ill.	C. R. Cross. Jas. B. Cahoon. D. W. Shea.
FROST, JOSEPH W.	Secretary, National Automatic Fire Alarm, 335 Broadway, New York City.	G. H. Stockbridge. Jos. Wetzler. R. W. Pope.
GARRELS, W. L.	Student, Westinghouse Electric and Mfg. Co.; residence, 4531 West Pine Boulevard, St. Louis, Mo.	Fred'k Bedell. Ernest Merritt. H. J. Ryan.
GILMORE, LUCIEN H.	Assistant in Physics, Stanford University, Palo Alto, Cal.	F. R. Medina. F. A. C. Perrine. Geo. P. Low.
GRIST, JAMES E.	Mechanical Engineer, Phila. Traction Co.; residence, 918 North 44th St., Philadelphia, Pa.	H. S. Hering. F. Uhlenhaut, Jr. C. A. Bragg.
HISS, WM. J., JR.	Senior in Electrical Dept., Lehigh University; residence, 28 Market St., Bethlehem, Pa.	W. H. Powell. R. W. Pope. E. Caldwell.

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JONES, HENRY C.	Member of firm, the Electric Construction and Supply Co., Montgomery, Ala.	A. E. Worswick. A. F. McKissick. C. H. Smith.
LARRABEE, ROLLEN N.	With the Western Electric Co.; residence, 30 W. 25th St., New York City.	H. F. Albright. G. A. Hamilton. E. S. Keefer.
MIDDLEMISS, P. R.	Post Graduate Student, Mech. and Elec. Engineering, Tulane University, New Orleans, La.; residence, 1616 Felicity St.	Brown Ayres. A. M. Schoen. R. W. Pope.
MORA, MARIANO L.	*C. E., E. E.*, 63 West 70th St., New York City.	F. B. Crocker. Max Osterberg. W. H. Freedman.
MOSMAN, CHAS. T.	Electrical Engineer, General Electric Co ; residence, 58 Washington Ave., Schenectady, N. Y.	C. P. Steinmetz. H. M. Hobart. H. G. Reist.
MERSHON, RALPH D.	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	C. A. Terry. H. A. Craigin. F. N. Waterman.
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co ; residence, 227 Mount St., Baltimore, Md.	E. J. Houston. A. E. Kennelly. Louis Duncan.
PATTON, PRICE I.	Sheble & Patton, Ltd., 1022 Arch St., residence, 3926 Walnut St., Philadelphia, Pa.	F. Sheble. Knowles Perot. C. M. Blanchard.
SHOCK, THOS. A. W.	Electrical Engineer, Electric Light and Power Co., Sacramento, Cal.	Geo. P. Low. F. F. Barbour. W. F. C. Hasson.
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 So. 3d St., Philadelphia, Pa.	A. E. Kennelly. E. J. Houston. W. C. L. Eglin.
STRATTON, ALEX.	With Crocker-Wheeler Electric Co., N. Y.; residence, 2013 5th Ave., New York City.	F. B. Crocker. Max Osterberg. W. H. Freedman.

Total, 20.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, December 17, 1894.

POWELL, WILLIAM HENRY	Electrician, Mather Electric Co., Manchester, Conn.
KIMBALL, ALONZO S.	Professor of Physics and Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.
MIX, EDGAR WOODS	Electrician, Thomson-Houston International Electric Co., Paris, France.

Total, 3.

At the same meeting the returns from the nomination sheets sent in by the various members were canvassed by the Council, and the following ticket was prepared, to be known as the Council ticket, as provided by the Rules:—

For President, Dr Louis Duncan of Baltimore.
For Vice-Presidents, Dr. M. I. Pupin of New York City, W. F. C. Hasson of San Francisco, A. S. Hibbard of Chicago.
For Managers, Carl Hering of Philadelphia, Bion J. Arnold of Chicago, Charles F. Scott of Pittsburg, Dr. Cary T. Hutchinson of New York City.
For Treasurer, George M. Phelps of New York City.

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The regular ballot sheet will be sent out by the Secretary, as required by the Rules on or before the 15th of April, and, as usual, will contain, in addition to the Council ticket, the names submitted by the members for the various offices. This, of course, enables every member to vote for any candidate he may select, under what is known as the Australian system.

THE PRESIDENT:—If there is no other business which the meeting wishes to take up now, we will proceed to the regular business. I take pleasure in introducing Prof. Harris J. Ryan, who will read a paper on "A Method of Preventing Armature Reaction."

PROF. RYAN:—By way of introduction, I wish to call your attention to certain points in connection with orthodox practice, in the design, construction, and operation of direct current dynamo electric machinery. In the first place, you all remember that it is necessary, in order that a proper commutation fringe at all working load outputs be maintained, that a proper reluctance of the air-gap be used in machinery usually designed for incandescent lighting, or for purposes where the load output fluctuates seldom and very slowly, so that the attendant can be depended upon for the gradual shifting of the brushes as the neutral point changes. Here smooth bodied armatures are used, and the length of the air-gap is so adjusted that it is necessary to place as initial ampere-turns—for producing that flux through the armature which is necessary for the normal pressure to be developed by the armature, that number of ampere-turns that shall be greater at all times than the ampere-turns on the armature at any particular load. Now, that did very well, when one followed out that rule for the construction of machinery that should operate in practice for incandescent lighting with success, and with smoothness as to commutation, ease in the commutation fringe, and in general behavior. But later on was developed, of course, on account of the demand for railway power supply, a generator that would supply a power load that would fluctuate very much through very wide ranges, in very short amounts of time; and you could not depend at all on an attendant to be present to shift the brushes into an easy and proper position of commutation, and it was necessary to so design this machine that sparkless commutation, so far as possible, at any rate, could be obtained at all load outputs without shifting of the brushes. Without the carbon brush, this could never have been accomplished. With metallic brushes it makes no difference even if one does adhere to the rule of maintaining an excitation from pole-face to pole-face, a magnetomotive force that will always be ahead of the armature ampere-turns, and even if one does maintain a positive fringe for commutation of a considerable value, you would have sparking with metallic brushes at no load, if you had no sparking at full load, or the reverse of this. The carbon brush was applied with very material success, and if Mr. Steinmetz, at the Philadelphia meeting, had had a little more time probably he would have called

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your attention to its use in commutation, in addition to the very interesting remarks that he made on the beneficial results that are obtained by maintaining a positive fringe by the use of saturated lugs in the ironclad armature. In the first place, it will be remembered from the discussion in connection with one of the papers at the Philadelphia meeting, that Mr. Steinmetz called the attention of the members present to the fact that if you use saturated lugs, normally saturated lugs, in an ironclad armature, you might then use a comparatively small air-gap and that the lugs would not allow, (when you applied series ampere-turns) the induction to be increased by the application of those series ampere-turns, which you know are necessary in order that a fringe shall be maintained positive. Series ampere-turns, if we have small initial ampere-turns—that is by initial ampere-turns I mean those ampere-turns that will bring the induction up to the normal at no load—and they are always small, of course, if we have a small air-gap; now if we apply series ampere-turns on the field in proportion to the load, we can very easily adjust those series ampere-turns, so that the magneto-motive force from pole-face to pole-face will be ahead of the armature ampere-turns at all times. But we have to contend with this troublesome feature that is introduced, if we do not design the machine to guard against it: that the induction will come up with the application of such series ampere-turns, which you remember are applied for the purpose of maintaining a positive fringe under the leading pole corner, so as to have the machine commutate as well as possible, at least under the load, without bad effects at the brushes. Now it was explained at that time by Mr. Steinmetz that if one saturates these lugs, (see Fig. 24 as used at board), that you would in that way keep the induction from being increased under the trailing pole corners, while you might allow it to be diminished a little bit under the advanced pole corners, and the relations adjusted in such a respect that you could add on series ampere-turns in this way with this small air-gap in such amount that the impressed ampere-turns under the leading pole corners at all loads would be ahead of the armature ampere-turns. In that way you would have a positive fringe and no danger, even on very heavy overloads, of having it come to zero or reverse with corresponding disruptive effects, which always occur at the brushes. With metallic brushes, even under those circumstances we should have a very bad behavior, and it is in connection with the points involved in the use of carbon brushes that I now want to engage your attention. If you can keep up the fringe then, (or the induction under the leading pole corners) to a considerable extent, a very fair fraction of the normal induction throughout a large portion of the range of load, unless there are too many ampere-turns on the armature, you can depend on the resistance of a carbon brush for reversing the current. First of all you can push a carbon brush over into the

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neighborhood of a pretty large portion of the commutative fringe, or the induction in the leading pole corner, and on account of its resistance, not have much current circulate in the coils passing the point of commutation. And then again when the current comes up under load, and pressure is needed to reverse the current on account of the self-induction of this section, as a bar is passing out from under a carbon brush the section in contact with the carbon brush, with the bar having the current in the right direction coming from this side, (indicating with the use of Fig. 24,) with the conductors moving in that direction, that section grows smaller and smaller every instant, and finally is nothing as it passes out from under; that current density eventually goes very high. The current has not yet been reversed in the neighboring coil. It must be reversed, however, com-

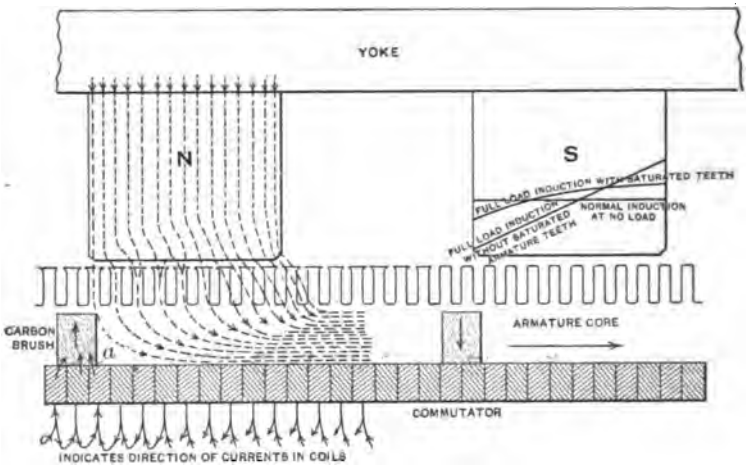

Fig. 24. (On blackboard.)

pletely, and brought up to the full value of the normal before it passes out, if any disruptive effect is not to occur. Now as this goes on, a very considerable local fall of potential occurs there (at *a*, in Fig. 24) and diverts a very appreciable amount of the pressure of the armature against the current that is in this coil in the former direction that it had on this side of the brush, and in that way the current is made to reverse through the action of the resistance of the carbon, and is the great reason why the carbon brush works with such wonderful smoothness on the old smooth-bodied armature where there is very little self-induction in the sections, and works with greater smoothness by far than any special metallic brush you could apply with the power generators, with the ironclad armatures, for the substantial mounting of conductors.

And then, while we are at this point in connection with ortho-

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dox practice, it seems to me that the tendency at the present day is so far as possible to do away with those T-shaped teeth. That increases the self-induction of the section to a very considerable extent. Now these teeth are made in that shape for two purposes, one is to prevent the fluctuation of the induction density in the pole-piece, and that of course must be prevented when the pole-piece is not laminated; and the other is, that by using the T shaped lug you are able to mount in a very mechanical and workmanlike manner the conductors on the armature. But a part of these teeth can be made T-shaped, and the remainder straight, and in that way the self-induction of the section is reduced very materially over the present practice, or rather the practice. at any rate, that has been in vogue within the last two years. You find the makers nowadays in many instances resorting to the use of a field core, made up entirely of laminated iron, or pole-pieces of laminated iron; or again, with these solid pole-pieces, straight lugs are used in recent designs, and the air-gap distance so adjusted that the Foucault current effects, the eddies developed in this pole-face, are such that desirable results are obtained.

Now I have called your attention to the fact that in all of this orthodox practice, the practice by means of which definite and the best results are obtained to-day, it is necessary to use the field ampere-turns somewhere, that will be ahead in magneto-motive force impressed between the pole-faces ahead of the armature ampere-turns at any load, if best results are to be obtained. And in the paper we shall look into the use of coils that will annul the effect of the conductors along the surface, and will see how, when that is done, the ampere-turns that are applied on the field, are only those that are necessary to set up the induction regardless entirely of any of these commutative requirements. In other words, one has the same magnetic conditions to look out for in estimating the excitation forces, as you have in an alternator that is free from self-induction in its own armature circuit, and is working on a non-inductive load. You are quite free from armature reaction effects, and a very small excitation suffices. These pernicious cross-leakage effects that occur with the use of deep grooves and saturated lugs under the trailing pole corner (indicated in Fig. 24) are quite obviated, so that woven or sectioned conductors are not necessary. The output of machines, all-told, has been increased through the application of such considerations very materially.

(Prof. Ryan then read the following paper.)

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A paper presented at the Ninety-fifth Meeting of the American Institute of Electrical Engineers, New York, President Houston in the Chair, and Chicago, Mr. S. Arthur Rhodes in the Chair, March 20th, 1895.

A METHOD FOR PREVENTING ARMATURE REACTION.

BY HARRIS J. RYAN AND MILTON E. THOMPSON.

In the designing of continuous current dynamo machinery, probably nothing has presented so much difficulty as the problem of avoiding the various evils resulting from the magnetic effects of the current that passes through the armature of the machine. Such magnetic effects are usually spoken of as armature reaction. These evils are at the present time well known, and pretty well understood by the electrical fraternity in general, and the modern dynamo designer who is not thoroughly well posted on the subject, would be wholly unable to design machinery capable of successful competition with some of the machines now on the market. The tendency of the currents that circulate in the armature coils is to produce a cross magnetism through the core at right angles to the natural field, resulting in a distortion of the natural field of the dynamo,—a piling up of the magnetic lines under the trailing pole corners, and a weakening of the field under the leading pole corners. This distortion of course, increases with the current furnished by the machine, and if not specially provided against, it may result in bringing the trailing pole corners to complete saturation, and in completely reversing the field under the leading pole corners. While this distortion is no great evil in itself, the resultant effects may be, and usually are very serious evils. All distortion of the natural field of a dynamo is sure to be attended by a diminution of the field strength resulting in a falling off of the E. M. F. produced by the dynamo, and if the distortion be very great, no amount of compounding will cause such a dynamo to give constant potential. The most serious evil,

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however, arises from the fact that the weakening of the field at the leading pole corners results in a shifting forward of the neutral point or diameter of commutation of the dynamo. The amount of such shifting depends on the amount of distortion, and this in turn varies with the load on the machine. Consequently if the brushes are set on the normal neutral point when running light, the machine will spark badly under load, and it becomes necessary to keep shifting the position of the brushes to meet every variation in load. More than this, unless the pole tips or armature lugs are saturated, a point of loading is soon reached, beyond which one finds no diameter of sparkless commutation, and the output of the machine has reached a maximum at this point, notwithstanding the fact that the load may be below that allowed by a safe heating limit. These facts as before stated, are well understood by the more competent dynamo designers, and receive the

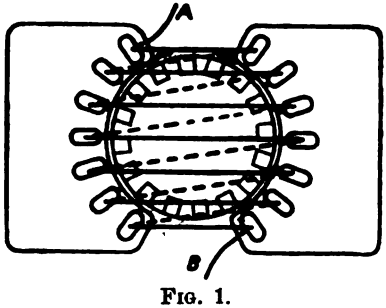

FIG. 1.

most careful consideration in the preparation of new designs. It must be confessed, however, that the principal part of the knowledge on this subject is the result of dearly bought experience and costly experiments, rather than of scientific study of the principles involved. Designers of dynamo machinery, with few exceptions, instead of aiming to prevent armature reaction, have endeavored to avoid its bad effects in various ways, and in some cases with fairly good results. The distorting effects of armature reaction become less, in proportion as the reluctance of the air-gap and armature core teeth are increased, and the wiser designers of the present day, taking advantage of these facts, are producing some very creditable machines. Probably some of them still believe, as some of the very best authorities on the subject of dynamo machinery have confessed to believing until quite re-

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cently, that armature reaction is a necessary evil, and if it were possible to prevent it entirely, the whole utility of the machine would disappear at the same time.

While making a thorough consideration of the subject of armature reaction some time since, one of the authors of this paper, devised a means of entirely preventing armature reaction and resulting field distortion. On looking up the literature of the subject we found, mainly through the patent office records, that there were several workers in the field at a comparatively early date, viz.: Prof. Elihu Thomson, Messrs. Andrews and Spencer, Mather, Forbes, and possibly one or two others. The specifications given by Andrews and Spencer indicate clearly the technical side of this method for preventing armature reactions, while

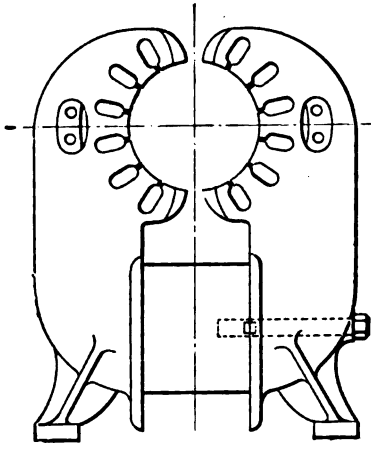

FIG. 2.

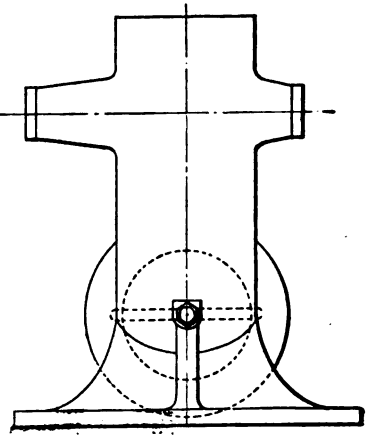

FIG. 3.

our part appears in the development of a plan for the practical application of the scheme technically outlined by them in 1886. This method consists in general in surrounding the armature with a stationary winding exactly similar in its magnetic effects to the armature winding, but directly opposed to it, and thus completely balancing all armature reaction. Fig. 1 is a diagram that shows the manner in which the coils are applied. Holes are provided immediately back of the pole surfaces, and through these holes are wound conductors which are placed in series with the armature. *The number of ampere-turns of the balancing coils crossing each pole face is equal to, and opposite in direction to the number of ampere-turns on the corresponding part of the armature.*

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A small bi-polar machine of about 2½ kilowatts capacity was designed, constructed and tested during the spring and summer of 1891, and the results obtained were very encouraging, demon-

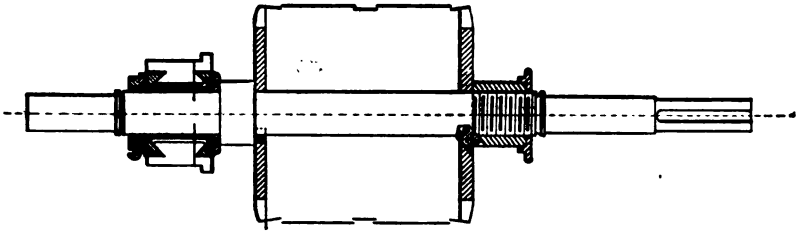

FIG. 4.

strating beyond doubt the correctness of one's understanding of the principles involved. Since that time some half-dozen or more multipolar machines of various sizes have been designed and constructed. All employ these balancing coils with various modifi-

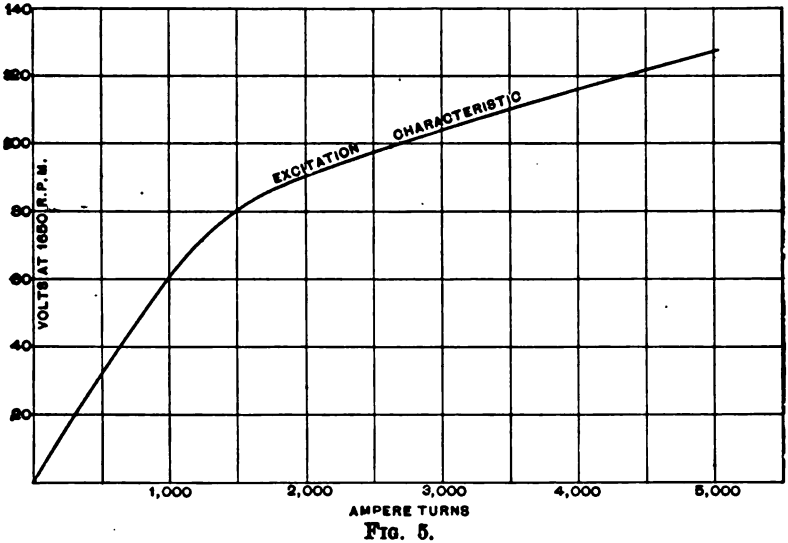

FIG. 5.

cations of design and gave the following results.

Brief mention of these results have been made heretofore in the literature, while a complete report of the same is now made for

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the first time.[1] Figs. 2 and 3 are side and vertical views of the first machine; Fig. 4 is a side view of the toothed armature; and the following are the essential data of construction:

Field of cast-iron, two poles	
Diameter of the armature core over all	6 in.
Length of armature core	6 in.
Number of teeth	64
Number of commutator bars	64
Armature turns per bar	3
Size of armature conductor, B. & S. G.	12
Resistance of armature, ohms	.34
Speed, R. P. M	1800
Output, amperes	25
Output, volts	100
Turns on field, 250 of No. 7, B. & S. G	
Balancing turns, wound in six grooves per pole face, 16 turns per groove, or a total of 96 turns of No. 8 B. & S. G.	
Resistance of balancing coils, ohms	.24

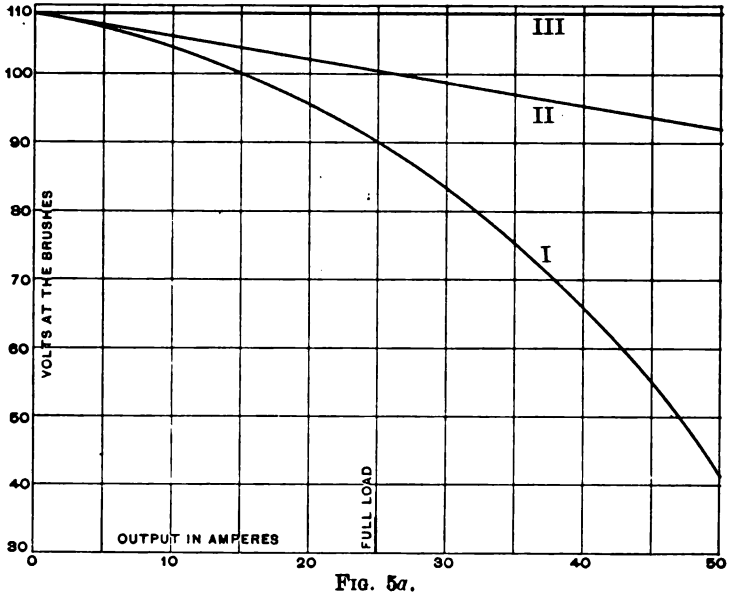

FIG. 5*a*.

For dimensions of slots to accomodate balancing winding see Fig. 2.

The diagram of Fig. 5 gives the excitation characteristic at no load and a speed of 1660 R. P. M. Fig. 5*a* is a diagram of results

1. "On a Method for Balancing Armature Reaction," *Sibley Journal of Engineering*, Oct. 1892, vol. vii, p. 17. "Electromagnetism and the Construction of Dynamos," by Dugald C. Jackson, p. 172.

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obtained by actual observation made on this machine when overloaded at normal excitation and speed, with and without the balancing coils. The pressure readings were taken at the brushes, and do not include the drop through the balancing coils when they were used. Characteristic I was obtained without the use of the balancing coils; characteristic II with the balancing coils; and characteristic III is the same as II with the balancing coils, when corrected for drop in pressure due to armature resistance. The same field excitation of 2600 ampere-turns was maintained at all times. It should be noted that without the balancing coils

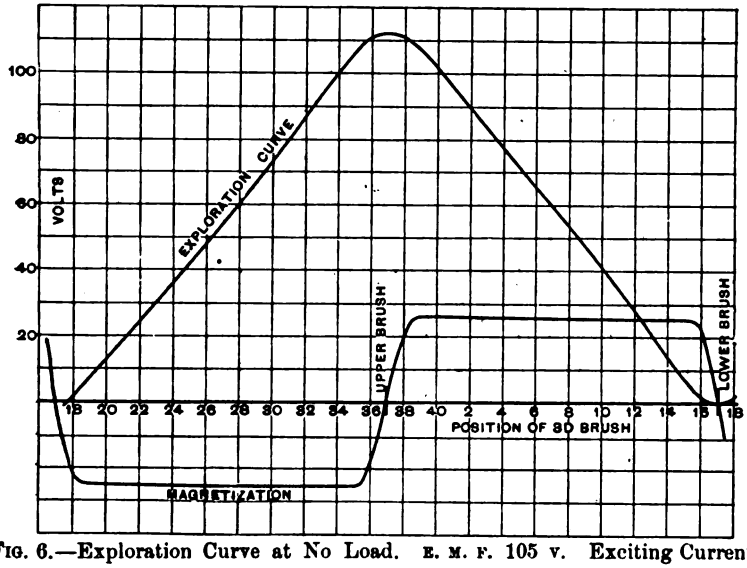

FIG. 6.—Exploration Curve at No Load. E. M. F. 105 V. Exciting Current, 10.4 C. Speed, 1,800 R. P. M. Operated as a Motor, Without Balancing Coil.

the pressure falls off uniformly and rapidly, from 109 volts at no load, to 41 volts at a load of 50 amperes, with violent sparking at all ranges of the overload. The potential differences due to the resistances of the carbon brushes were not nearly enough to reverse the currents in the coils while under the brushes, against the opposing E. M F.'s produced by the reversed fields established by the powerful armature reactions. The E. M. F. at the brushes falls off with a rapidity that is greater than that which would be due alone to the resistance of the armature, because of the throttling action of those parts of the magnetic circuit that become

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saturated by the concentration of the induction by the route of the trailing pole corners. In marked contrast was the corresponding behavior of the machine with the balancing coils in circuit, as illustrated by curve II. There was no sparking at any point of the overloading; the brushes were fixed on the no load position, *i. e.*, at the zero of field induction, and at all loads the currents in the sections were easily reversed without spark, by the potential differenees that were caused by the resistance of the carbon. There was no observable falling off of the induction

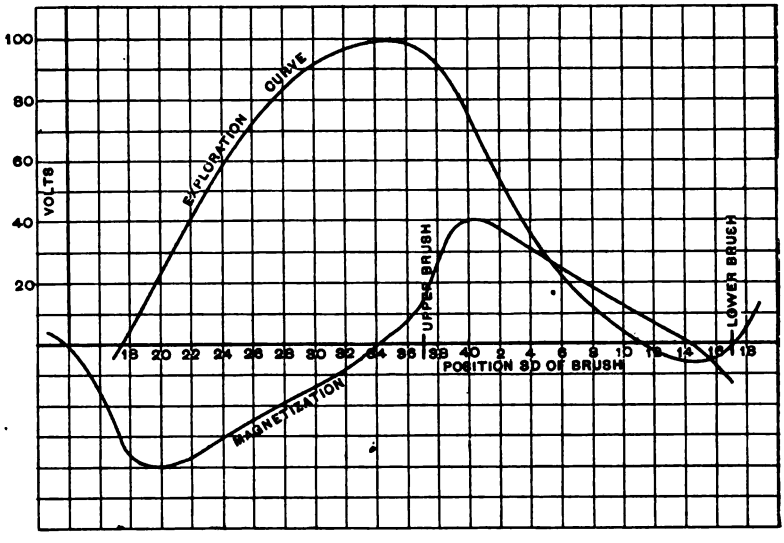

FIG. 7.—Exploration Curve, Full Load. V. = 97. C = .24. Exciting Current, 10.4 A. Speed, 1,800 R. P. M. Operated as a Dynamo, Without Balancing Coil.

through the armature under load when the balancing coils were used; and this is clearly indicated by curve III, which as stated before, is curve II corrected for the fall of pressure due to the resistance of the armature.

The diagrams with their respective legends that are given in Figs. 6 to 14 inclusive, are self-explanatory. Separate excitation was used on all the experiments on this machine. The pilot or third brush method was used for making the field explorations. In each instance the "exploration curve" is a record of the pilot brush readings, while the ordinates of the "magnetization" curve

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are proportional to the actual induction densities as deduced from the exploration curve. Fig. 6 shows that the induction is uniform over the entire pole-face at no load, normal excitation and speed, as it should be without the coils. The motion of the armature conductors is from right to left. Fig. 7 shows the production of a reversed field in the presence of the brushes at a full load current, and normal field excitation without the balancing coil. Fig. 8 gives the result obtained for the same conditions, except that the balancing coil was used. The magnetization curve shows that the balancing coil slightly over-compensated the

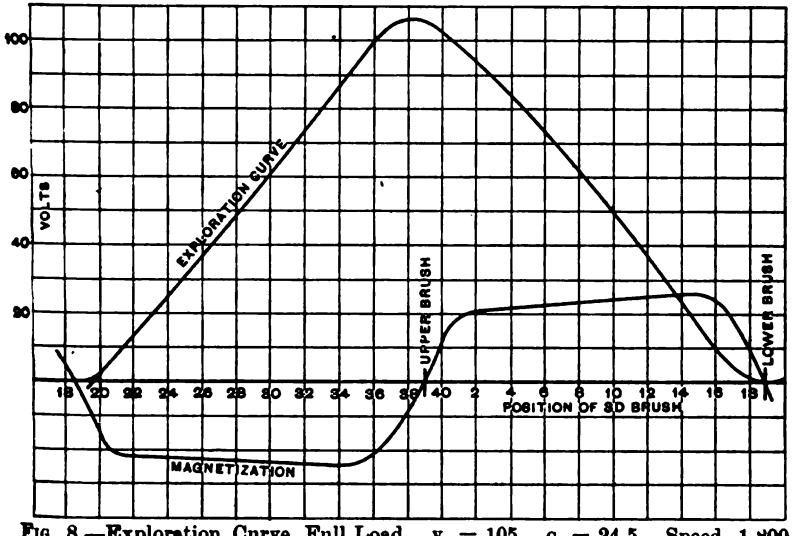

FIG. 8.—Exploration Curve, Full Load. V. = 105. C. = 24.5. Speed, 1,800 R. P. M. Exciting Current, 10.4. Operated as a Dynamo, With Balancing Coil.

magnetic action of the armature, since the induction of the trailing pole tip is weakened, and that of the advanced tip strengthened, a phenomenon just the reverse of what commonly occurs. The diagrams of Figs. 9 and 10 are for substantially the same conditions as those of 7 and 8, except that the machine was operated as a motor. The results are precisely those one would expect—the same as those obtained for the dynamo, except that the sides on which the higher inductions occur are reversed in position. Figs. 11, 12, 13 and 14 give interesting results that were obtained by lowering the field E. M. F. and then operating as before. By ope-

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rating as a dynamo or motor without the coil, extraordinary powerful armature reactive effects are produced. It is seen that the brushes are in the presence of a reversed field that is quite as great as the normal no-load field of 3000 lines per square centimetre, and moderate sparking with the carbon brushes occurred. Here the balancing coils bring out an interesting effect. One would expect that the effects of their over-balancing action would be felt more at lower excitations. In this experiment the induction at the advance pole tip or the position of the "commutation

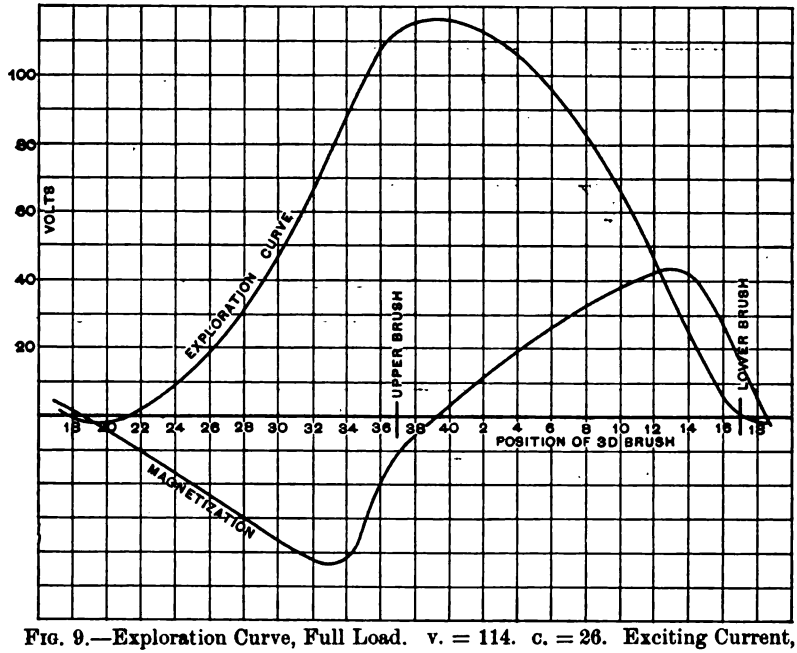

FIG. 9.—Exploration Curve, Full Load. V. = 114. C. = 26. Exciting Current, 10.4 A. Speed, 1,920 R. P. M. Operated as a Motor, Without Balancing Coil.

fringe" is almost doubled from the normal no-load value instead of being diminished as is ordinarily the case. It is appreciated that the effect of such a behavior is to increase the strength of the commutating fringe at the leading pole tip in proportion to the load, thereby diminishing the range of change of the non-sparking point with metallic brushes, or enabling carbon brushes to be easily adjusted so that when in a fixed position there will be practically no sparking at all ranges of load.

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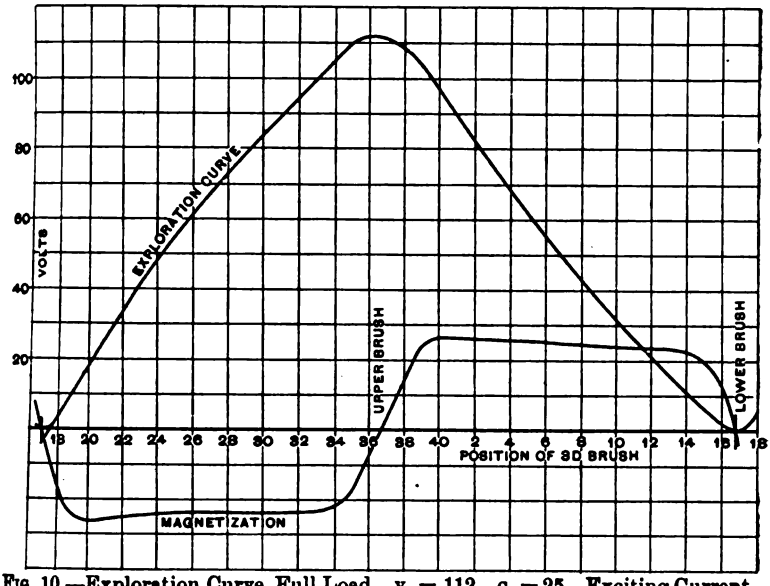

FIG. 10.—Exploration Curve, Full Load. v. = 112. c. = 25. Exciting Current, 10.4 A. Speed, 1,920 R. P. M. Operated as a Motor, With Balancing Coil.

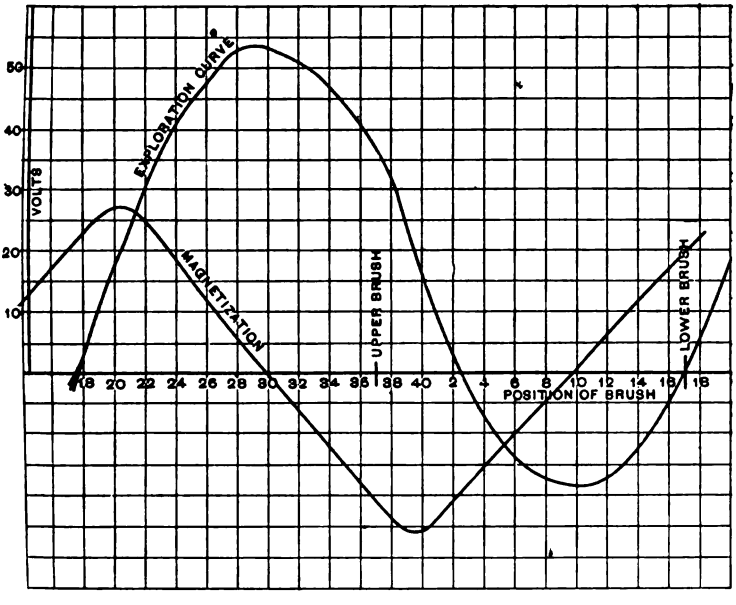

FIG. 11.—Exploration Curve, Full Load. v. = 36. c. = 20. Exciting Current, 2.5 A. Speed, 1,800 R. P. M. Operated as a Dynamo, Without Balancing Coil.

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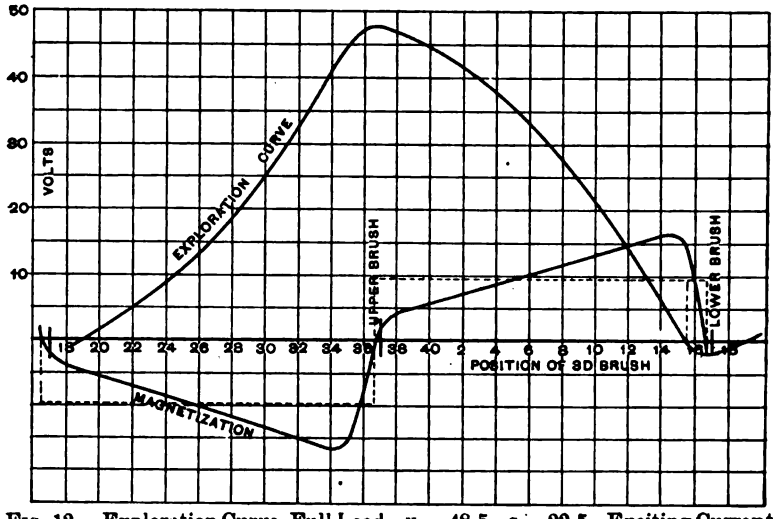

FIG. 12.—Exploration Curve, Full Load. v. = 48.5. c. = 22.5. Exciting Current, 2.5 A. Speed, 1,800 R. P. M. Operated as a Dynamo, With Balancing Coil.

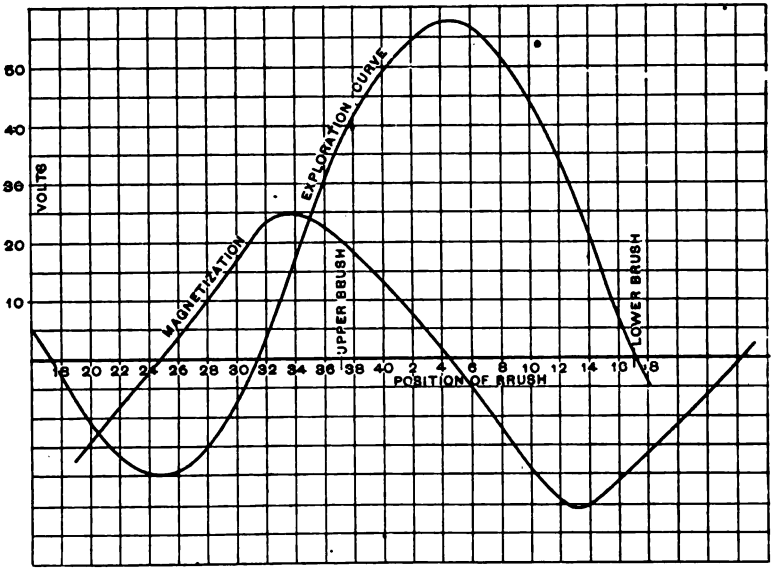

FIG. 13.—Exploration Curve, Full Load. v. = 36.5. c. = 23.5. Exciting Current, 1.6 A. Speed, 1,600 R. P. M. Operated as a Motor, Without Balancing Coil.

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The second machine that was built, and which made use of balancing coils, was a small one of the four-pole type with cast-iron field magnets. This machine was designed to have a capacity of 25 amperes at 80 volts, or 2 kilowatts when running at a speed of 1,200 revolutions. Fig. 15 is a diagram that shows the general design of the machine, and Fig. 16 is made from a photograph of the actual machine. The essential features of the design were as follows: Type of machine, 4 pole; field, cast-iron in two pieces. Armature two circuit drum winding through 58 grooves; 5 No. 10 B. & S. G. wires in each

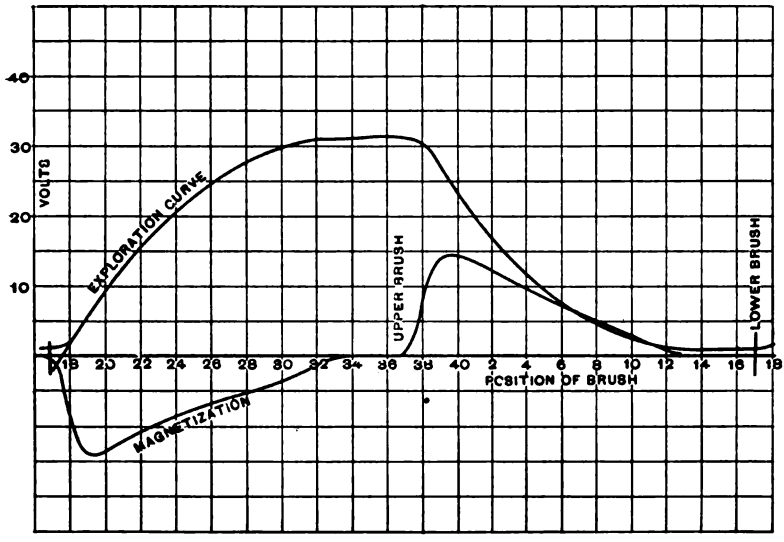

FIG. 14.—Exploration Curve, Full Load. V. = 31. C. = 24. Exciting Current, 1.6 A. Speed, 1,520 R. P. M. Operated as a Motor, With Balancing Coil.

groove; 29 commutator bars; grooves milled out, size $\frac{5}{8}'' \times \frac{9}{64}''$; outside diameter of core $7\frac{1}{2}''$, inside 3″, surface of completed armature wound with No. 14 B. & S. G. iron wire. Length of armature and poles, 6″ each. Effective length of iron in armature core, 5″, magnetic leakage, 15 per cent. Field cores, 5″ x 2″, with rounded ends; area, 9.14 square inches. Mean length of field magnetic circuit, 12.5 inch. Magnetic density in armature core, 5,400 gausses; in air-gap, 4,900; in the armature teeth, 8,400; in the field cores, 6,800. Field winding, mean length of turn, 15 inches, requisite exciting M. M. F. for field circuit, 1145

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gilberts; for armature, 31.3 gilberts; for air-gap, 1258 gilberts; or a total of 2,434 gilberts; size of field wire, No. 18 B. & S. G. Number of holes for balancing coils, five in each pole-piece, seven conductors per pole or 140 conductors total. Weight of complete machine, 400 pounds.

An examination of this data discloses the fact that no regard is had for the pernicious effects that are ordinarily met with in the use of so short an air-gap with a comparatively large number of armature ampere-turns. With the use of the balancing coils no such effects were observed; the machine performed precisely in accordance with the original estimate made in designing it, and exactly as theory shows that ordinary machines would perform if armature reaction were entirely absent.

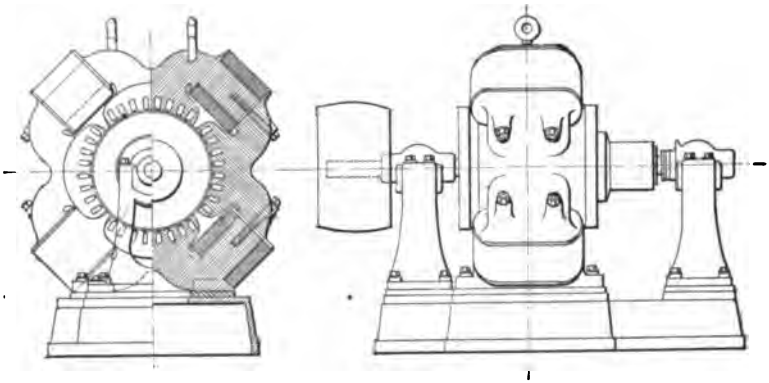

FIG. 15.

During test the machine was belted directly to a ten H. P. Sprague motor, and ran at a speed varying from 1,500 to 1,650 R. P. M. The commutator was quite small for a four-pole machine; it had only 29 segments and was very poorly suited for the pressure of 100 volts at which it was tested. The machine was loaded down to 43 amperes at 100 volts, speed 1,650, and an exploration curve taken around the commutator. This curve is shown in Fig. 17 and clearly indicates the entire absence of field distortion. It was found that the machine would easily carry a load of 45 amperes continuously without overheating. After this curve was taken, the machine was loaded down as heavily as the driving belt would permit, and ran at a load of 80 amperes and 80 volts for about fifteen minutes. Under this load there

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was no appreciable difference from light load in the behavior of the commutator. The balancing coils were short-circuited for an instant while the machine was loaded to 40 amperes, and the vicious sparking that ensued, showed that the dynamo could not be operated at this load without the balancing coils. Indeed the indications were, that it would have been fatal to the welfare of the commutator, and perhaps to the armature itself to entirely cut out the balancing coils when the machine was carrying this load. The balancing coils were then cut out and the dynamo gradually loaded down to test the performance without balancing

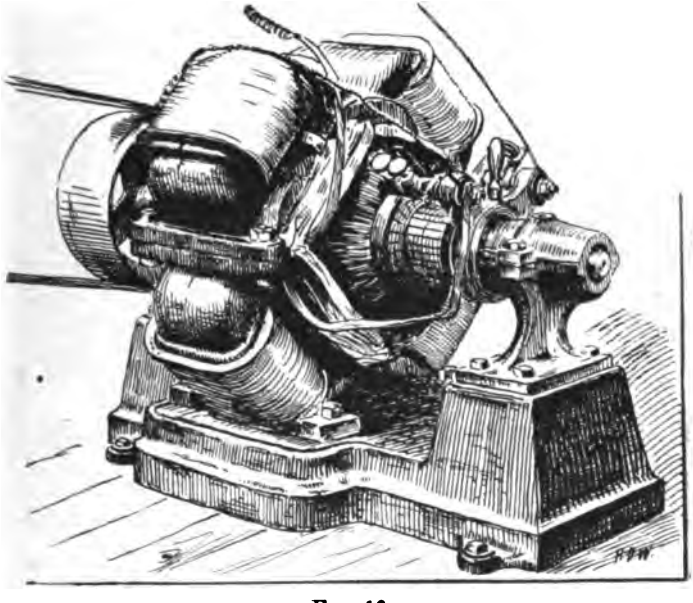

FIG. 16.

coils. The brushes were shifted forward to prevent sparking as the neutral point changed, and the potential was kept up as much as possible by cutting out field rheostat. The maximum current reached was 37 amperes at 85 volts, with field rheostat all out, and speed 1,800 R. P. M. At this speed, and with this excitation, the machine would have given 120 volts, instead of 85, if the balancing coils had been used to prevent armature reaction. After a load of 37 amperes was reached, it was found impossible to raise the current by cutting down the external resistance, owing to the rapid fall of potential due to armature reaction.

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The capacity of this particular machine was about doubled by the addition of the balancing coils, and a comparison of the 37 amperes maximum with the 80 amperes which was by no means the highest possible current, shows that the overload capacity of this machine may be doubled by their use.

Two more machines of the same general design as the latter were built and tested. These machines were built with field magnets of mitis metal, and the pole-pieces and armature cores were one inch longer than the machine last described. The armature windings were different from each other and different from the cast-iron machine. One was wound with a two circuit winding, and the other with a four circuit winding. Total weight of each machine was 450 pounds. Each machine, after

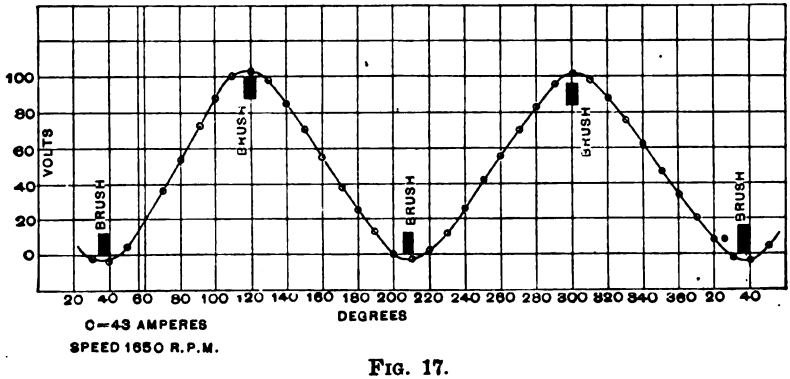

FIG. 17.

running at 1200 R. P. M., carried a load of 85 amperes at 110 volts for two hours continuously, and was then loaded down to 100 amperes for a quarter of an hour. The performance of the machines confirmed in every particular the results previously obtained.

Two other machines of this same type were built,—one of which was wound for a current of ten amperes at 600 volts, and the other for a current of 550 amperes at 110 volts, or 60 kilowatts.

This type of machine was found to be expensive to construct, and owing to its exceeding compactness, very hard to ventilate. The main plan in view when designing these machines was to lessen

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the total weight for a given output by taking advantage of the fact that when the balancing coils are used, one may greatly increase the amount of copper on a given armature, and still obtain the same satisfactory performance at the commutator. As Fig. 15 indicates, a too compact design was adopted; the ventilation was cut down so that full benefit of the large amount of armature copper was not obtained.

Machine No. 7 was therefore built with a field of the ring type. This machine embodied a number of important improvements in details of construction as will be hereafter noted. Fig. 18 shows a photograph of the machine from the pulley end, and Fig. 19 is a view from the commutator end. Fig. 20 is a view of the arm-

FIG. 18.

ature which was wound with No. 6 wire cable. Both commutator and armature core were hollow, and the winding thoroughly ventilated. All armature coils were wound simultaneously, and the winding was perfectly symmetrical. Fig. 21 is a view of the pole ring. This ring which carries the six balancing coils was made in halves, and the pole-pieces were joined together by small connecting lugs as seen in the figure, in order to make the casting continuous. This construction permits the field coils to be wound in a lathe, and to be easily removed from the fields at will. It is also a decided advantage to have the balancing coils and the pole-pieces through which they are wound, separable from

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the rest of the field. The following are the more important details of the design of this machine:—Capacity, 91 amperes at 110 volts or 10 kilowatts. Type of machine, six-pole, ring field of steel. Armature winding of cable through grooves in core. Armature ten inches in diameter outside, by five inches inside; number of grooves, 61,—six conductors per groove. Grooves, $\frac{7}{32}''$ wide by $1\frac{1}{4}''$ deep; number of commutator bars, 122; total number of conductors, 366. Armature core and pole-pieces, five inches

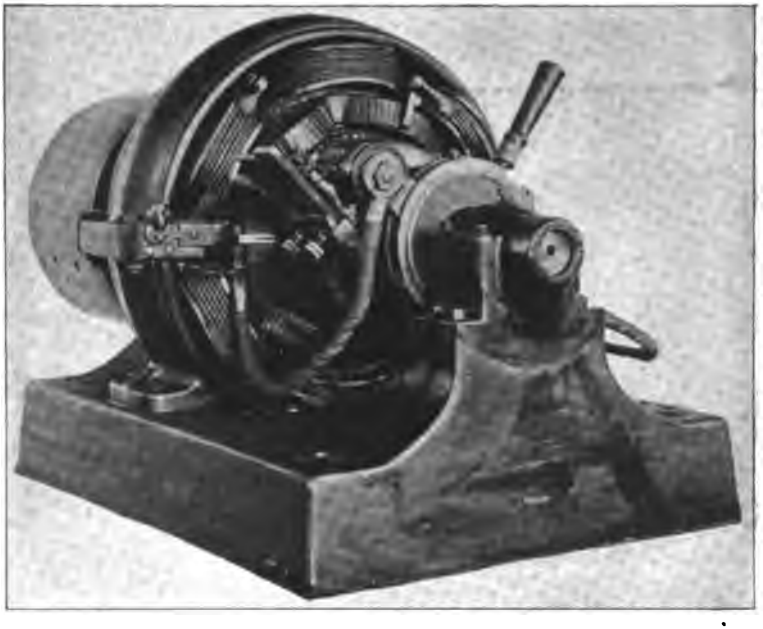

FIG. 19.

long. Mean distance between poles, $\frac{3}{4}''$. Total magnetic flux, 1,800,000 webers; maximum density in armature teeth, 14,400 gausses. Maximum radial density in armature core, 8,500. Mean air-gap density, 5.000. Maximum field density, 14,000; length of air-gap, $\frac{1}{16}''$; M. M. F. for field, 642 gilberts; for air-gap, 1,600 gilberts; for armature, 99 gilberts; total M. M. F., 2,341 gilberts. Fields wound with No. 20 B. & S. G. wire. Armature, 366 conductors of No. 6 cable; five holes in each pole-piece for balancing

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coils. Balancing coils wound with copper ribbon. Compounding, two series turns on each field coil.

Weight of field casting, actual	213 lbs.
" " armature core, shaft and spider	98 "
" " " and commutator complete	185 "
" " " copper	48 "
" " copper for balancing coils, actual	55 "
" " field copper, actual	40 "
" " dynamo complete including base bearings, brush holders, brushes and 14 × 9 inch pulley	865 "

This machine was completed and tested in October 1894, and the results of test were as follows: Speed of dynamo, 1,065 R. P. M.; voltage, 110. Current, 110 amperes. Time of run, one hour. Temperature of room, 71° F. Temperature of armature,

FIG. 20.

128° F. Temperature of field, 108° F. Rise of armature, 57° F. Rise of field, 37° F. Field resistance, 110 ohms. Field current, 1.00 amperes. Field energy, 110 watts. Armature resistance, .0512 ohms. Armature winding loss, 618 watts. Balancing coil resistance, .0202 ohms. Balancing coil loss, 242 watts. Series resistance, .00955 ohms. Series loss, 115 watts. Core loss, friction, etc., obtained from energy absorbed as motor running light at full pressure, 450 watts. Total losses, 1,408 watts. Total output, 12.100 watts. Gross energy absorbed, 13,508 watts. Commercial efficiency, 88.7 per cent. For lighter loads the efficiencies are given by the curve in Fig. 21*a*. This test was made after the machine had been running for several hours under various loads. On another occasion the machine ran one hour and twenty minutes under a load of 115 amperes at 105 volts with a rise of

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temperature of armature of 48° F. While carrying this load, which it will be noted is 25 per cent. above the rated full load, the pilot brush exploration curve, shown in Fig. 22, was taken. This curve shows the entire absence of armature reaction. The machine has also carried 135 amperes for one-quarter hour, and has several times been loaded down to 180 amperes for a few minutes at a time without damage.

While the "balancing coils," as may have been seen from the foregoing results, entirely prevent field distortion and shifting of

FIG. 21.

the neutral point, there is still something lacking for ideal commutation. In a constant potential dynamo, the following are the conditions for perfect and sparkless commutation. When a coil is short-circuited as it passes under a brush, the current in the coil must fall to zero, reverse, and rise exactly to the original value in the opposite direction at the instant the short circuited coil is opened by the passage of the tip of the brush from the commutator bar. To bring about this reversal properly, the short-circuited coil must move during short-circuit through a field whose strength is proportional to the armature current. In other

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words, the short-circuited coil should move in a neutral field when the machine is unloaded, and should move in a field of considerable strength when fully loaded. The field strength required for sparkless commutation under any particular load depends first on the resistance of the short-circuited coil; second, the self-induction of the short-circuited coil; and third, the duration of the short-circuit which in turn depends on the width of brush and speed of the dynamo. Preferably the short-circuited coil should move in a uniformly distributed field. It is evident from this consideration that we do not get the conditions for perfectly sparkless commutation even where armature reaction is prevented

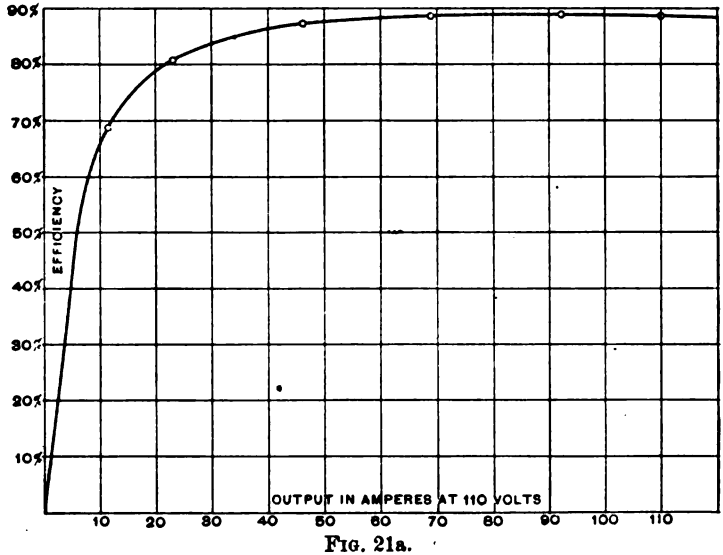

FIG. 21a.

if we attempt to commutate under pole corner. It is also evident that if armature reaction and field distortion *are* not prevented, we get just the opposite effect on our commutation from what we would wish—that is, our commutation field grows weaker as the current increases, instead of growing stronger as it should. From this we may set it down as a settled fact, that no dynamo of any considerable voltage and range of capacity which commutates under the leading pole corner and is not provided with some special spark preventing device or arrangement for preventing field distortion can be worked from no load to full load without sparking or without shifting the brushes. During

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their experimental work on balancing armature reaction, the writers devoted considerable time to the problem of sparkless commutation, and as a result have devised an improvement to be used in connection with balancing coils, by means of which ideal commutation is attained. The device is simple, and accomplishes the desired end perfectly. It consists in bridging across the gap between the pole-pieces, attaching a commutation lug to the center of this bridge and making this lug the center of the balancing coil, the latter being provided with a few extra turns, The arrangement is shown in Fig. 23, which represents a portion of the field circuit sectioned centrally in the plane of rotation. Referring to the figure, *aa* and *bb* are two field coils wound round the pole necks C and D; G is the commutation lug which is at-

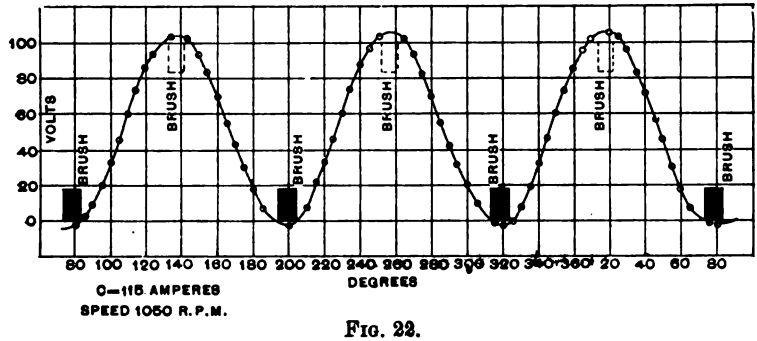

FIG. 22.

tached to the middle of the lugs H I, which latter bridge across the gap between the pole-pieces E and F. The balancing coil (not shown) is wound through the holes K, L, M, N, O, P, with the commutation lug G at the center of the coil. The path for magnetism is indicated by the dotted lines. It will be noticed that a part of the magnetic lines are shunted across between the pole-pieces E and F, through the bridge lugs H I, and do not pass through the armature. Now when there is no current in the armature or balancing coils, it may be easily seen that the fall of magnetic potential from E to F is the same by either the path through the bridge lugs, or through the armature, and that the commutation lug G attached to the middle of the bridge lugs, must be at the same

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magnetic potential as the armature teeth opposite, for the latter are connected to the middle of the armature circuit. Therefore, under these conditions, which are practically what we have when the machine is running light, there will be no field between the surfaces R and S of the commutation lug and armature respectively. If then our brushes are set so that commutation takes place while the short-circuited coil is passing under the commutation lug, we have the correct conditions for sparkless commutation. When the machine is loaded, the excess of ampere-turns of the balancing coils over ampere-turns of the armature, brings a magnetizing force to bear on the lug G in the direction indicated by the arrow.

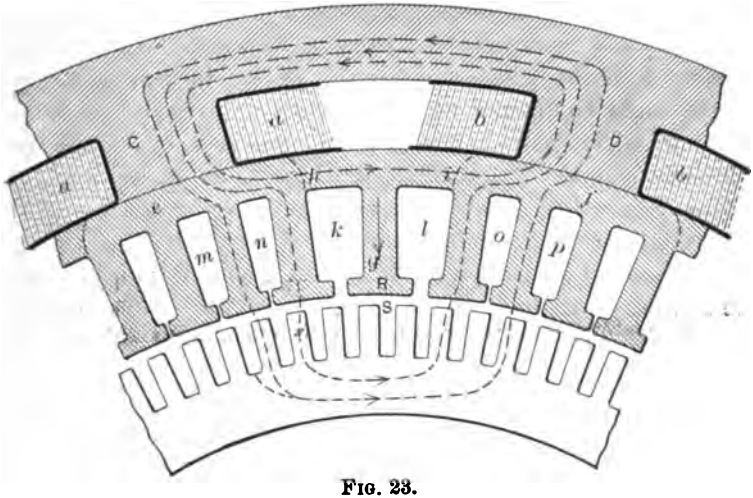

FIG. 23.

This tends to increase the magnetism through H and diminish it through I, but as H is normally saturated, there will be very little increase in its magnetism. There will, however, be a field established under the commutation lug, by the deflection of the lines from the bridge lug I through the commutation lug and armature, and it is evident that the stronger the current in the balancing coils, the stronger will be the field under the commutation lug. We, therefore, again have the correct condition for sparkless commutation when the machine is loaded, provided our balancing coils are so proportioned as to give us a commutation field of proper strength. From this it will be seen that at all times the

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commutation field is proportional to the current, and that for all loads we have the requisite conditions for sparkless commutation without shifting the brushes.

So much for the theory of this plan, and now comes the important question "Will it work in practice?" We are able to answer without hesitation that such a machine performs as well in practice as in theory, and that actual tests show absolutely sparkless commutation from no load to 50 per cent. overload with fixed metallic brushes. More than this, practice confirms another theoretical advantage of this improvement which we have not yet touched upon. It will be noticed that the commutation field is obtained by the deflection of lines from bridge lug 1 and that the lines so deflected, pass through the armature, and consequently are added to the useful magnetic field. We might expect from this, and from the fact that since the brushes are midway between the poles, there are no back ampere-turns, that the machines would compound somewhat without a regular compound winding. This theory was entirely sustained by actual trial. It was found under test, that by slightly shifting the position of the brushes forward or backward, it was possible to make a few of the armature turns act with, or against the field winding at will, and this without any effect on the sparkless commutation, so long as the brushes were not moved beyond the limits of the commutation field. The result of this is that by simply shifting the brushes, the compounding of the machine may be so changed that it can be adjusted at any point from 10 per cent. drop to 10 per cent. over-compound, and this without interfering with the commutation in any way.

Thus by this simple contrivance we attain sparkless commutation without shifting of brushes, and a compounding adjustable at will. It is not claimed that the broad idea of a commutation lug is new, but the success of such a contrivance depends altogether on the way in which it is applied. Unless the magnetic effects of the armature currents are taken care of properly, a commutation lug would prove worse than useless and we would be likely to get an effect just the opposite of that desired. Thus it will be seen that the advantages which we have shown as resulting from the use of this system of commutation, arise not from the use of a commutation lug alone, but from its use in connection with coils for balancing armature reactions. Direct experiment has shown that this system of commutation will not

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give satisfactory results except when used in connection with balancing coils. Aside from the effect on commutation, however, balancing coils have some very important advantages to which we will briefly call attention. By their use the capacity of a machine of given size and weight may be greatly increased, and the resulting machine still be far better in quality and operate more satisfactorily than those of ordinary design. The reasons for drawing this conclusion are briefly these: Since the output of these machines is in no degree limited by armature reaction, it is possible to load the armature with as much copper as can be crowded onto it and to work this greatly increased amount of copper to its safe heating limit,—the heating of the armature conductors being the only limit to the capacity of a given armature; and the core losses may be much less in a machine of this type since the magnetic densities in the core may be made as low as we choose, and this will permit the armature to be loaded with still more copper.

With the standard peripheral velocity of 3,000 feet, it is easy to get an output of 20 to 30 watts per pound total weight of dynamo, and for large sizes of machines even still greater output per pound. With armature reaction balanced, there is no necessity for high reluctance in air-gap and teeth, and it is therefore made as low as possible for the whole magnetic circuit. The air-gap is reduced to what suffices for clearance, and the armature and field are worked at as low densities as is consistent with economy of iron. By this means from one-half to three-fourths or even more, of the ampere-turns on the field may be saved with a corresponding saving in field copper and field energy. This, and the reduced core losses reduce the fixed losses in the dynamo to a minimum, bringing them below what is possible with the ordinary construction, and the result is a very material change in the shape of the efficiency curve of the machine. Since the fixed losses are very small, the machines will have unusually high efficiency on light loads, the efficiency curves run up very sharply and bend off to a very uniform efficiency throughout the greater part of the range of load. This is a very decided advantage where machines are expected to work under considerable range of load as they usually are, both for lighting and power purposes. In designing machines it is also an easy matter to proportion materials according to their relative prices. Thus, with a design containing a given amount of copper, we can increase the copper

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slightly and reduce the iron and steel, keeping the capacity of the machine the same, and thereby effect a saving in cost perhaps, or we may increase the iron and steel and reduce the copper to effect a similar saving. With ordinary designs such an adjustment as this would be out of the question, except at a sacrifice of valuable qualities of the machine, for the invariable rule is that the M. M. F. of the armature ampere-turns may never exceed the M. M. F. impressed by the field between the pole faces.

The value of sparkless commutation is almost beyond price. Commutation has long been recognized as the greatest bugbear of continuous current machinery. Whatever adds to the life of the commutator adds to the durability of the machine, and the entire prevention of sparking is, therefore, an important feature. To be able also to have the brushes permanently fixed is of decided value, and this when taken with sparkless commutation makes a dynamo self-attendant to a greater degree than usual. The extra cost of applying these improvements to a dynamo is far more than balanced by the saving effected in materials, and the writers believe that the application of these methods of design in dynamos would make a pronounced and important step towards the practical perfection of this class of machinery.

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Discussion.

The President: This valuable and interesting paper is now open for discussion.

Mr. Townsend Wolcott:—It is interesting to notice the evolution of the dynamo, the differentiation of species, you may say. Those of us who have been in business for a number of years remember when dynamos were nearly all of one class, or at least there was very little difference between the different classes of dynamos. At first we had the old series machine. The first departure from that was the shunt machine, then the compound. Then we had the perfect regulation with the constant potential dynamo, then for a long time it was supposed that we could not have a constant current machine which gave perfect regulation without a regulating mechanism of some kind. Just about this particular time a machine of the opposite kind from the one we have just been hearing about is brought into public notice. That is a machine where the armature reaction is carried to the greatest extent for the purpose of regulation. That is the new Brush machine which has been developed by Mr. Black. In Prof. Ryan's machine which we have just been hearing about, the armature reaction is absolutely prevented. On the other hand, in the arc machine, the armature reaction is exalted to a very great degree for the purpose of getting the other kind of regulation. The desirability of entirely suppressing the armature reaction, perhaps, could not be questioned for a constant potential machine if it did not require the use of extra wire, etc. Perhaps it will be used as it is, but I think a great many dynamo designers are very certain that they can use the armature reaction to advantage even in shunt machines. For instance, it has been the hobby of some dynamo designers for some time, that shunt motors can be made to work satisfactorily, and regulated by means of the armature reaction, just as well as the compound motor with the shunt in opposition to the series coil, and, as a matter of fact, there are a great many shunt and compound machines, as at present built, which are not troubled with sparking.

Mr. W. L. Bliss:—The paper read by Professor Ryan this evening is certainly very interesting, and of considerable value and I, for one, wish to thank him for it. I had the pleasure of being one of Professor Ryan's students at the time when he built his first machines with reactive or balancing coils, and under his direction made a number of experiments upon the same, which in all respects of operation, concur with what he has presented this evening.[1] In this manner I became quite familiar with the subject of armature reaction. But since I have gone out from under his care and guidance, I have been rather inclined to go astray in the matter of balancing armature reaction. It

1. *Sibley Journal of Engineering*, December, 1892; *Electrical World*, January, 7,'93.

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seems to me that there must be some commercial impediment that precludes a more universal adoption of the methods outlined tonight. In the first place it is either on account of the additional cost of preparing these devices, and applying them to machines, or secondly the additional output does not warrant such expenditure, or lastly, if we do use these devices we are almost certain to interfere with some one's patent. It is the object of the manufacturer to patent as many useful inventions as he can for himself, and to dodge as far as possible, those of other people. We know that these schemes for balancing armature reaction are all bound up in the Patent Office, and consequently we can hardly censure manufacturers for not having utilized them. Their failure to use them is probably not a lack of knowledge upon the subject, but on account of commercial considerations.

To take up the various points in order:—Professor Ryan says that the poles have to be made particularly heavy for this kind of construction; and as we notice from the cuts of the machines he has presented, the poles are brought very close together. It seems to me that making the poles so exceedingly heavy adds weight and expense. Increasing the proximity of the poles must cause a considerable increase in the magnetic leakage which has to be made up by extra copper placed upon the fields and extra energy expended therein, while cutting holes through the faces of the poles seems to me to have a sort of throttling action on the field flux and reduces the useful cross-section of said poles that might otherwise be utilized to advantage. However, we are told that by filling up these holes or slots with the proper windings, and allowing the total current to circulate through them, we can overcome our armature reaction. The truth of this statement is borne out fully by experiment. We are also told that the clearance in large machines may be reduced enormously by the aid of such windings. I think, though, it is evident to nearly every one who sees large machines in operation, that a great deal of clearance is necessary, particularly in direct coupled machinery, on account of the excessive wobbling of the armatures. This clearance is far beyond that which would be necessary if the machine could be run perfectly steady and true, without the danger of a mishap to such a complicated and somewhat delicate structure as an armature. This air-gap may be nearly or quite sufficient to cause sparkless running, so why go to farther complication? These points should all be considered in estimating the value and advisability of adopting devices for balancing armature reactance.

I have here a few notes made in reference to the output of a machine, in watts per pound. Prof. Ryan states that the output of a machine can be brought up to a very high figure, and that the watts per pound of material can be made as great as 20 or 30. He speaks here about a machine that was designed for two kilowatts, and weighed 400 pounds, and had a peripheral velocity of 3,000 feet. This is only 5 watts per pound. We built at our

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factory, some time ago a motor designed to operate a launch. It was of the 4-pole salient consequent type, completely iron-clad, and could be placed under water with impunity. The total weight was 185 pounds, and the maximum capacity 3.8 kilowatts, which you see was 20.3 watts per pound. This machine operated with an armature 6 inches in diameter by 4 inches long, which you see is quite small, and yet the number of watts per pound was 20.3. This machine had a peripheral velocity of only 1,500 feet per minute and operated with a commutator of 45 sections, on which were set two brushes. The maximum current taken out of the commutator was 85 amperes, through a carbon brush about $\frac{3}{8}$ of an inch thick, and 2 inches wide. The motor ran in both directions on account of the service it was placed in, and could be operated under full load one way, or full load the other way without any shifting of the brushes. There was absolutely no sparking at the brushes. The brush-holders were bolted rigidly to the casing and there was no possible chance to shift them.

To illustrate further a case in which the armature reaction was not at all injurious, I will mention that for the last year or so I have designed machinery for car lighting purposes where the dynamo was driven by an axle connection. Here the object in view was to maintain the pressure practically constant on the lamps and on the storage batteries, at the same time utilizing a speed in the dynamo that varied from the time at which the dynamo was made operative, to the time at which the train was at the maximum speed, from 600 R. P. M., to 1,500 R. P. M., the latter figure representing a velocity of the train of about 60 miles per hour. Here we used a differential coil on the field magnets, through which the main current circulated, and which demagnetized the fields of the machine as the current and speed increased. And yet with these machines, using armatures 6 inches in diameter, by 6 inches long, which is exactly the same size as given in Prof. Ryan's paper, we were able to load down the machines to over 2 kilowatts, demagnetize the fields fully one half, and still they were sparkless, had fixed brushes and ran in both directions, which was evidently necessary on account of the service. We were able to accomplish these results without the use of balancing coils. When we first went into this extremely exacting work, we seriously contemplated using some armature reactive device, but we found we did not need it. It was at this time that we looked up the patent records and secured so much valuable information on this subject.

MR. E. A. MERRILL:—I would like to suggest that there are one or two points, which if covered, would make the paper a little more complete. You can take a high resistance brush and place it on the commutator in a position where the field is stronger than is required to reverse the current, yet without sparking; so if you had a dynamo which would give 115 volts

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with the brushes correctly placed, the brushes might be so placed as to give an effective voltage of only 110 without sparking, so that 5 volts is wasted; this is corrected by the balancing coil.

There are some interesting curves here. Take the curve on page 91. I think it would have been instructive if Prof. Ryan had added curves, showing the effect of the balancing coils with decreasing field excitation, the maximum voltage decreasing in proportion, for with this coil you can get almost down to zero volts, certainly down to five or six, with curves exactly similar to the exploration curve on page 91, but diminishing in maximum height. This method gives a full control of the voltage and the output from the maximum voltage to the minimum without distortion of the field.

Then it seems to me it is a little unfortunate that curves 11, 12, 13 and 14 follow each other as they do. Fig 11 shows the dynamo without balancing coil, and Fig. 12 the dynamo with balancing coil. It might be assumed from one following the

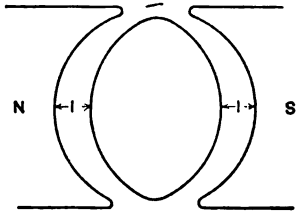

FIG. 25.

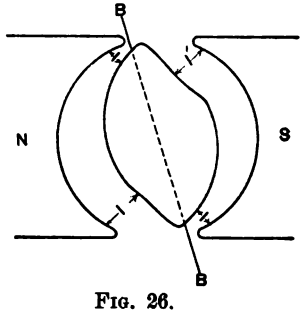

FIG. 26.

other, that the magnetization curve in Fig 12, was the necessary result of the use of the balancing coil. As a matter of fact, it is not the necessary result, and you would not get that curve if the balancing coil were designed to give the curve shown on page 91. The magnetization curve in Fig. 12 simply illustrates the fact that you have complete control of the distribution of magnetization in the pole-face and that you can take a pole-face with a weak pole, say at the top, and a strong pole at the bottom and reverse it; but if the same number of ampere-turns had been used in the balancing coil as in the armature, it would have given a uniform induction through the armature, and the same is true of the two curves, 13 and 14.

Then, if I could use the blackboard a moment, there is another method of plotting the magnetization, which makes it a little more graphic, and that is to plot the relative induction through the armature on radial lines, the depth from the pole-face to the curve representing the relative induction through the armature at all points. For example Fig. 25, shows for every

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point in the pole-face very graphically the relative induction, and by plotting it for different field excitations and armature currents it shows the distortion produced by the armature current and also very plainly the effect of the balancing coil; the distance 1 from the curve to the pole-face on radial lines showing the relative induction through the armature. This figure shows the induction at no load, and is practically uniform over most of the pole-face, diminishing to zero midway between the poles. If a strong current is passed through the armature, the curve may assume the form shown in Fig. 26. The induction at 1, as you see, is very slight and in fact may be reversed under certain conditions. The induction at 1^1 is very strong, showing that these pole-tips are saturated. Now, if in addition to that, you indicate the position of the brushes and line of commutation at B, it shows graphically the strength of the field in which the commutation and reversal occurs, and it also shows on which side of the zero point it occurs, showing whether the voltage tends to be increased or diminished. Now, if curves were drawn in this way, showing the effect of the balancing coil, and also of the commutation lug, with the position of the brushes shown, you would get an excellent idea of the relative induction at every point, and of the actual effect which the balancing coil and commutation lug exert.

Dr. Cary T. Hutchinson:—It seems to me rather interesting that there have been two attempts made recently to get rid of sparking, one by Mr. Sayers, of England, and the second by Prof. Ryan here. Mr. Sayers, instead of doctoring the field, puts an extra winding on the armature connected between the commutator bars of the coil to be short-circuited. This was found to work only in one direction. So recently he made an addition by putting on a commutating lug—a sort of postscript. Prof. Ryan starts with a balancing coil, and finds it does pretty well. But it does not answer under all circumstances. So he too adds an additional commutating lug. It is rather amusing to see that both should follow the same line. The first ideas are more or less ineffective; then they are improved to meet the conditions. I think that both of them are fundamentally wrong. There are so very many interesting points in a paper like this, that it is impossible to touch upon them all in an evening's discussion. But one thing in particular, I think, should be emphasized strongly. The fact that the output of any armature properly designed does not depend on sparking. Sparking is evidence of bad design, and should condemn the machine without regard to any other consideration. Any one taking this view will see at once that no device of this kind can increase the output of the machine in the slightest degree. It decreases the output of the machine for the reason that the extra winding takes up space that would be valuable. It adds weight; it adds copper. I hold the point of view that any machine, properly designed, will not

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spark; and as a sort of comparison with this machine, I wish to give some figures of a machine which is in use in the city here, of the very simplest design. that does not spark under any conditions, short of the abnormal. It has no Sayers device and no balancing coils. It impresses me that the use of a balancing device is as if a man, wishing to walk along on a level, should walk up hill 150 feet and then down again. The armature effect takes you down, and the balancing coil brings you up. The machine described on page 101 is the largest mentioned, and it makes a fairer comparison than the others with the one I am about to describe. That machine may be taken normally to be 12 kilowatts. It has a total weight of 865 pounds. Leaving off the last item and adding the other weights, you will find that the "active" weight is, say, 740 pounds. The machine runs at a peripheral speed of a little over 2,800 feet a minute. Making this 3,000 feet for the purpose of comparison would mean an output of 17 watts per pound of active weight, with, of course, the balancing coils. There is pretty nearly as much copper in the balancing coils as there is in the main field coils. The machine I have in mind is of the ordinary Continental type, with two field coils, two salient poles and two consequent. It is a 30 kilowatts. Its total weight is 3,300 pounds, and its "active" weight is 2,600 pounds. It runs at a peripheral speed of only 1,500 feet per minute. Calculation will show that its output for that active weight is about 12 watts, roughly, at 1,500 feet per minute. Doubling that would give an output at a peripheral speed of 3,000 of, say, 24 watts per pound active weight. It is a plain ordinary machine, nothing special about it, and will carry 60 to 70 per cent. overload without a sign of sparking, without showing whether the current is on or off. Should we, however, make the comparison on a slightly different basis, referring still to page 101, it shows even more strongly in favor of the point I am making. You will notice that the watts lost in the armature proper in this machine are given at 618. The proportions of the two machines are very nearly the same, one, 10 × 5, the other 18 × 10. Assume that the radiation in my armature is the same as in the armature described here, and that, therefore, my armature could carry a current determined only by this heating; this would give 200 amperes, which it has carried without sparking. The output of the machine then would be 38 watts per pound active weight at 3,000 feet per minute. It seems to me that it is unnecessary to use the methods described here; that it is going back to archaic ages; for, in my opinion, any machine that needs this doctoring is fundamentally wrong. I believe a machine, instead of being designed with weak field excitation and low induction, should be designed on opposite lines, with strong excitation and heavy induction. One might think this would increase the weight of the copper in the fields and bring up the total cost of the machine. As a matter of fact, I find that the

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weight of the copper, with the balancing coils, in the machine described on page 101 is 12.8 per cent. of what I call the "active" weight. In the machine I speak of, the proportion of field copper is only 10.1 per cent. It is an ingenious exercise, and not much more. Referring in the same way to another point, that the gap induction should be as low as possible, I take the opposite view, that it should be as high as possible.

There are quite a number of other points that one might bring up for discussion, but I will not take more time.

MR. CHAS. S. BRADLEY:—I am quite interested to know that there are machines which do not spark. I have heard of those before. Generally, however, I have found that they existed in the ideal of the manufacturer. Almost every man declares when he has constructed a new machine that there is no sparking whatever, But just as soon as anybody undertakes to use it, and the commutators get the least rough then they begin to spark, and I never saw one yet that did not spark, although I would go a good many miles to see one.

DR. HUTCHINSON:—Will you come up and see me to-morrow?

MR. BRADLEY:—I will be very glad to. I would walk ten miles to see one that did not spark.

DR. HUTCHINSON:—Come to the Postal Telegraph Company's building, 253 Broadway.

MR. BRADLEY:—Do you take care of it all the time?

DR. HUTCHINSON:—No, I never see it.

MR. C. O. MAILLOUX:—The paper read by Prof. Ryan is one which has undoubted merit in the beauty of its theory and the perfection of its experimental demonstration of the principle involved, whatever may be the practical commercial value of the invention. The point which was made by the preceding speaker is well taken in one sense, in regard to the heating limit, and it would apply particularly to this machine, because the ventilating space around the armature is so much reduced. There is little chance for convection or the motion of air currents by means of which heat can be dissipated. I have found that to be a strong objection, and one which has a direct influence on the heating limit of the machines. In fact, insufficient air circulation is more apt to reduce the capacity, in consequence of the heat limit being sooner reached, than is any excess of heating caused in the pole-pieces themselves by the eddy currents due to variations of magnetic density by the action of the teeth of the armature. In other words, the loss in dynamos caused by the eddy currents and the consequent heating in the machine frame, etc., is not as serious as is the reduction of the output capacity of the machine in consequence of its not being able to ventilate itself properly. One may, therefore, have a machine which, so far as the copper is concerned, would be very far removed from its possible capacity limit, whereas its practical capacity limit is sooner reached, due to the fact that it cannot dissipate the watts generated in the armature or pole-pieces.

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One of the most interesting points, in my opinion, which Prof. Ryan has called to our attention this evening, and one which must interest a large number of those present, is the question of density in the armature teeth, and the density in the air-gap itself. There are many here who cannot afford to throw away the designs and patterns they have for manufacturing, the dies for punching the armature disks, etc., and they cannot quickly or readily depart from existing commercial and well-developed or well-established as well as successful types; yet, within certain lines they are very eager to develop their machines without introducing any radical changes; and it is to them that the question appeals with especial importance. Prof. Ryan called attention to the fact, which is now recognized, that we can palliate the difficulties of armature reaction by increasing the magnetic density of the armature teeth. I mentioned before this INSTITUTE, some two years ago or more, that in my practice I had sometimes carried the density of lines of force in armature teeth to such a degree that the permeability came down to something like two or three. About two years ago I had occasion to have a special motor made, and my attention was called by the party who was furnishing me the disks, to the fact that the total equivalent sectional area of the teeth was rather small in comparison with the sectional area of the armature itself, or the available iron for the passage of lines of force in the teeth was a very small proportion compared with the sectional area through the armature core itself. He was somewhat surprised when I told him this was done on purpose. I explained to him that I believed in having the magnetic reluctance entirely in the air-gap. It did not make any difference whether we had it in air or in iron, provided it was there; though there are certain evident advantages in having it in iron as much as possible. I had observed that by using high saturation of the armature teeth, and high field density in the air-gap, it was possible to eliminate or palliate the difficulties resulting from armature reaction to a great extent, and consequently the machine became more sparkless, and had a higher load limit In making the teeth narrower or deeper to increase the magnetic density, we gain incidentally, in the space available for wire, and thus increase the capacity of the machine. This plan has its disadvantages and limitations, I will admit. But it seems to me to be a point of great interest and, on which there must be many persons here who have experience.

Another point which I would like to have some of the gentlemen here discuss, is the question of magnetic density in the air-gap per square centimetre. My own experience indicates that practically there is no limit to the air-gap density; it is merely a question of what one is willing to pay for it in the form of watts wasted in producing the magnetizing current. The higher the density in the air-gap, the greater the extent to which one is enabled to reduce the armature reaction and increase the output

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of the machine by making its load limit farther removed. With higher air-gap densities the air or extra-dental portion of the gap can be decreased without detriment. When I speak of the air-gap, I often include the total space between the face of the pole-piece and the bottom of the root of the tooth, or the inter-dental space. This is not as strange as it might at first seem, when you consider that in working at very high densities the permeability is approaching a value which is nearly that of air. In some calculations for special work, I have found myself obliged to take into consideration the joint reluctance of teeth and air space. Usually where such low densities are considered in the iron of the teeth, the number of lines of force—the number of square centimetres in the air of the air-gap between the armature teeth, (the inter-dental space) is of no consequence. But when you reach permeabilities as low as two and three, or even before that, the air itself between the armature teeth becomes a magnetic conductive medium of some importance. For that reason, it is perhaps quite as logical to treat the air-gap as if it were all air, with a portion of it more or less short-circuited, or having its magnetic reluctance enhanced by the presence of metal of higher magnetic conductivity.

The question is, I think, one of greater importance than might at first seem, and it has a great bearing on the question of good performance of machines and their output limit, consequently on their weight. I think it would be of interest to have the experience on that subject of many others here present.

Dr. Charles E. Emery:—I have made a large number of experiments on the general subject of armature reaction, and have seen the electromotive force reversed in a half cycle even worse than shown in the paper, where the polar surfaces of the field magnet were too large for the exciting force employed. With larger exciting forces the reversal did not take place. Referring to the proposed shifting of the brushes in lieu of compounding with coils, I frequently have been annoyed at seeing the tenders of the old bi-polar dynamos continually shift the brushes to try and reduce trifling sparks, with the result that the attendant on the switchboard platform had to make corresponding changes of his field regulators. In this connection I finally made a fairly elaborate series of experiments with modified windings designed to produce a neutral arc through which the brushes could be shifted for the purpose of compounding exactly as proposed in the paper. The sparkless arc was not successfully obtained, though the results were encouraging. About this time I had an opportunity to shift the brushes on one of the new General Electric generators when well loaded, and found that very considerable changes in the voltage could be obtained by shifting the brushes without producing sparking. It appears therefore, that dynamos are now so well designed that additional features would ordinarily not be warranted. If, however, the

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improved details now proposed, greatly increase the capacity, this will furnish the desirable commercial feature to enable one bidder to guarantee a given overload at a lower price than another.

In any event, Prof. Ryan, not neglecting the co-author, again deserves our thanks for a record of careful experiments, revealing the underlying principles of interesting and important phenomena, and it will be pleasing if the devices designed to overcome well-known difficulties prove of considerable commercial value.

Mr. A. E. Kennelly:—The question at issue in this case seems to be not the question of the number of watts which can be obtained per pound of material, or, at least, that is not the primary and essential question. The primary and essential question in an engineering matter must be, what is the number of watts of output that can be permanently sustained per dollar of investment in the machine, and per dollar of up-keep and yearly maintenance, including depreciation and repairs. We all know that dynamos and motors spark. It is always a question whether the output of a dynamo or a motor is reached in its heating before it is reached in its sparking, and one of the two conditions must supervene to limit the output of the machine. In the modern practice it is the heating which limits the output, and not the sparking. But that does not altogether settle the question, because if it can be shown that by differences in construction, or in superiority of methods of ventilation, the heating temperature of elevation can be reduced, to enable the machine to be carried forward to a greater limit of output, so as to bring the question of sparking under consideration, then there is room for any device which checks and prevents sparking. The question can only be decided it seems to me, by actual experiments, and by actual estimates based on such experiments. The only guide we have in the paper before us as to the actual results possible, is in the statement that 20 to 30 watts per pound of total dynamo weight can be obtained by the method in use, and, as a rule, whatever exceptional dynamos may do, that is a greater output than standard machines today possess. I think the figures given for this machine described in the paper do not show anything like such an output, so that I think the figures are based on estimates, and not based on actual experience. Many attempts, as we all know, as the patent records show, have been made to overcome armature reaction, very frequently by adding lugs over the point of commutation in the armature. But I do not remember seeing any method quite so radical as this, which consists in providing two armature windings, one of which is intended to rotate, and the other to remain fixed.

Turning to the purely technical side of the subject, an interesting question appears to arise. We know that when a smooth-cored armature is employed in a dynamo-electric machine, say a motor, the force which propels the motor when the electric current is

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supplied to the armature, *i.e.* the electro-dynamic force, is exerted on the substance of the conducting wires, and if they are not firmly secured to the armature body, th y are liable to be forced or sheared electro-dynamically over the armature surfaces. The only function of the armature core, from a magnetic point of view, is to reduce the reluctance of the magnetic circuit through the armature, and increase the intensity of the magnetic field which reacts upon the active conductors.

When. however, the armature is tooth-cored, and the same conductors lie deeply imbedded in the iron surface of the armature, it is, I think, the general belief that, since the conductors lie in a space comparatively unoccupied by flux from the field magnets—since the flux passes through the core of the armature without penetrating the substance of the conductors—that the current passing through these conductors magnetizes the iron of the core, and converts it, so to speak, into an electromagnet whose poles are attracted by the poles of the field magnet. In fact, it is sometimes claimed that the use of tooth-cored armatures not only prevents eddy currents from being developed in the armature conductors, but also removes from them the driving force, to the greater mechanical safety of their insulating coating.

In the experiments described in this paper, however, and as shown in Fig. 1, on page 85, the balancing coils, having a M. M. F., equal and opposite to that of the armature winding, must completely or nearly neutralize the magnetic influence of the armature winding upon the armature core, so that the iron of the armature does not become magnetized, like an electromagnet, by the action of the armature current. This is further evidenced by the series of observations presented in Figs. 10 and 17, in which it appears that the distribution of the flux over the surface of the active armature, is sensibly the same as when the armature remains inactive. From this it would appear that if the armature winding were mechanically free from the iron core in which it lies imbedded, it would rotate, or tend to rotate, with the full torque of the machine, leaving the core at rest within; also that the balancing coils attached to the field poles tend to rotate about the axis of the armature in the opposite direction. If this reasoning be correct, it would seem necessary to suppose that in this, and, therefore, in any tooth-cored armature, the electro-dynamic force is exerted upon the substance of the conductor and not upon the substance of the iron core, and I would like to ask Professor Ryan for the opinion he has formed upon this question from his study of the phenomena.

Mr. Gano S. Dunn:—With regard to the high densities in the teeth, I would call attention to the fact that such densities are necessary only when we depend on shifting our brushes to stop the sparking. But if in a machine of small size, we do not depend on such means, but depend entirely upon the resistance of the carbon brush to reverse the coil, then a high density in the

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teeth is a positive disadvantage, since it makes us have so much more magneto-motive force, or copper in our field coils In a small machine the field energy is a much larger proportion of the input than in a large machine, which makes this an important point: for by letting the density in the teeth remain low we save just so much of what is already a large loss.

Mr. C. O. Mailloux:—I would like to state in reply to the remarks made by Mr. Dunn that that statement does not necessarily always apply. I have found, in connection with the very machine which I refer to, which was run in both directions as a motor, that in spite of the very high density, with the set position of the brushes, there was no sparking, although the field excitation was not excessive. I think those things are largely a question of design. The design in this case was a four-pole machine of the consequent-pole type, similar to that which Dr. Hutchinson has described, and that may account in some manner for its wonderful performance.

With reference to the method of balancing devised by Prof. Ryan I do not quite agree with my colleague and friend, Mr. Kennelly, that it must be regarded as a stationary armature. I regard it rather, as strictly speaking, a system or set of compounding coils. I do not think we can regard it in any other way. And I think they are an ideal form of compounding from a theoretical standpoint. If we stop to consider compounding, we find that it means, substantially, to add enough extra coils so as to get an increased magneto-motive force sufficient to stiffen the lines of force and make them pass through their path, or to put it differently to overcome the added reluctance due to their distortion. Prof. Ryan finds that it is simpler to straighten them. He applies the force at right angles and merely restores the bent lines of force back to their position. I think if we investigate the forces in action, the final result is just the same as if we had a magnetic force acting at right angles with that of the field itself—or, strictly speaking, as Prof. Ryan puts it, in opposition to that of the armature. The armature tends to distort the field lines of force at right angles. It is a force acting tangentially to the armature; it bends the lines of force out of their course; Prof. Ryan simply bends them back. That, I think, is the ideal method because it always requires less force to produce the result, same as in mechanics, it is often simpler to use guys, and struts, instead of attempting to make the beam itself stronger and stiffer by increasing its size.

Mr. Maxwell M. Mayer:—I should like to ask the previous speaker, that, in case the density of the teeth is exceedingly high, so that the permeability of same is equal to the air, how the quantity of wire and the necessary energy wasted in fields, can be such a small amount as he has mentioned.

Mr. Mailloux:—I must correct the gentleman. I did not state that. The permeability is something like 25. I was refer-

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ring to other cases, such as street car motors, where it is not so much a question of saving copper as it is a question of space, and of the equally important matters of proper working under extraordinary conditions. I have not the figures in my mind of the machine I just mentioned, but, if I recollect rightly, the maximum permeability at the time of starting was something like 20.

MR. MAYER:—I should again like to ask Mr. Mailloux, or any of the gentlemen present, whether they consider using the teeth at very high inductions, and overcoming the armature reactions, more advantageous than using a low density, and decreasing the reluctance of air space to a minimum.

MR. MAILLOUX:—As I stated previously, I endeavored to have as much as possible of the reluctance in the air-gap. Of course, it goes without saying that the designer should always bear in mind the specific purpose for which the machine is intended, and that he should govern himself accordingly. What may be excellent for one case may be very bad in another case. I cannot answer the question of this gentleman because it would involve the analysis of a great many points, some of which are rather abstruse, while others would require access to comparative data.

THE PRESIDENT:—If there are no other remarks, I will call on Prof. Ryan to close the discussion.

PROF. RYAN:—I have been very much interested in the discussion myself. I have hardly anything to say, I think, in conclusion—possible one or two words.

I think Dr. Hutchinson was of the opinion that we advocated in our paper the lowest possible densities. Well, I meant by that, when you use the balancing coils, that of course then you do not need to resort to the very high induction densities in the lugs, in order to be able to add on series ampere-turns, without running up the induction and electromotive force of the machine. That is what we meant to refer to—what we had in mind when we wrote what we did.

With regard to the point mentioned by Mr. Kennelly, as to whether magnetic forces are brought to bear on the armature conductors when pole-face coils balance the armature reactive effects, or whether they are still on the armature lugs, I would explain what my own view is in connection with that matter, because it seems to me that this is a subject of a good deal of practical importance. If the forces, through balancing the reactive effect, are thereby made to be exerted on the conductors, then of course, one is reverted to a set of mechanical features which are not so desirable. It seems to me, however, that this force, even if one has balanced the effects entirely so that at all outputs of the armature the field is uniform for the pole-face and throughout the air-gap, that the forces are still a kind of drag on the armature core and not on the armature conductors, and the reason why I think so is this: It seems to me that the electro-

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motive forces that we get there are produced rather by the including and the excluding of induction in one direction, and then in the other direction through the armature coils as is the case in the transformer. The forces at work on the coils there are those more especially due to the proximity of two coils with currents in opposite directions. We all understand, I think, that great variation of induction occurs at high rates, and large electromotive forces are produced that set up no forces between the primary coil and the iron circuit. You may have such transformer coils carrying heavy currents at considerable pressures, representing large powers, and yet we ordinarily experience no mechanical action of the iron circuit on these coils. I see no reason why similar results may not be obtained in a dynamo. This is the view I have had of the matter, and I think it is an interesting point brought up in the manner in which Mr. Kennelly has presented it.

Dr. Hutchinson:—I do not see how the attraction can be on the teeth, as Mr. Kennelly suggests, for the reason that the magnetization of the teeth does not increase in proportion to the current in the armature, and the torque does. Therefore the pull must be on the conductor carrying the current.

[Adjourned.]

[Conclusion Communicated by Prof. H. J. Ryan.]

The 30 k. w. machine, cited by Dr. Hutchinson, is a Sprague-Pratt elevator motor, and one might as well try to discuss modern constant pressure direct current power generators by telling what one finds to be the performance, weights, etc., of the latest and best street car motors, as to cite the above excellent elevator motor. The same applies to the comparisons made by Mr. Bliss.

Mr. Kennelly has well stated what the experience of ourselves and others has been regarding the heating limit of an armature as determined by ventilation and that one finds when the ventilation is improved without sacrifice, the sparking limit may come within the heating limit.

Mr. Thompson has produced an armature design that affords ventilation of the conductors proportional to their number or depth on a given core. The output figures, 20 to 30 watts per pound, were based on the results of experiments made with a machine designed and built by Mr. Thompson and tested about the time when this paper was written. It was not described in the paper because it was not our object to discuss armature ventilation at this time.

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Discussion in Chicago.

A meeting of the Western members of the Institute was held in the Physics Lecture Room of Armour Institute, March 20th, on the same evening as the New York meeting. The Local Secretary, Mr. B. J: Arnold, called the meeting to order, about sixty-five members and visitors being in attendance. Upon motion, Mr. S. A. Rhodes was appointed Chairman. The paper of the evening—"A Method for preventing Armature Reaction" by Prof. Harris J. Ryan and Mr. Milton E. Thompson, was read in detail by Professor S. B. Fortenbaugh of the University of Wisconsin, at the authors' request.

Mr. B. J. Arnold:—I feel that this subject is something out of the line of work upon which I am posted, although I realize the importance of accomplishing the object the author has outlined. The chief objections to the kind of electrical machinery which engineers have had to use in the past have been the high rotative speed, and the difficulty of preventing the commutator from sparking under great changes of load. The main reason for using high speeds has been to enable the manufacturer to produce machines of large output at a cost within the reach of the purchasers. We are now, however, rapidly coming to regard slow running direct coupled generators as standard, and the competition among manufacturers, owing to the expiration of patents and the entering of new firms into the field has resulted in decreasing the price of dynamo-electrical machinery to a point which makes large, slow running machines available, at a cost not much in excess of belted machines. The question of no sparking at various loads, seems to me to have already been well met by the manufacturers, as, under specifications issued recently, and upon which four leading manufacturers bid, all guaranteed that their machines would not spark at all from no load to 50 per cent. overload. If they accomplish this, and it seems that some of them do by correct dynamo design, without the use of auxiliary coils, I see no reason for the introduction of them, as the author suggests, as it must necessarily increase the cost of the machine. I have no doubt, however, that the coils introduced as he plans them, will prevent an otherwise badly designed dynamo from sparking. The manner, however, in which the author has undertaken to prevent armature reaction is at least heroic, and reminds me of the manner in which Professor Thomson some years ago succeeded in preventing an otherwise destructive effect on his arc-lighting machine, viz:—the excessive spark across the air-gap on his three part commutator by introducing an air pump or blower to blow out the spark. This method was successfully introduced, and is in use on thousands of dynamos throughout this country to-day, although it now seems advisable to design arc light dynamos which do not produce sparking at the commutator at all, and therefore have no necessity for air blasts or other means for the external prevention of sparking.

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MR. A. V. ABBOTT:—There is no doubt at all but that Professor Ryan's method could be successfully applied, and he seems to have hit upon an invention which has been greatly needed. From a mechanical standpoint, dynamo constructors have endeavored to attain these conditions. This form of construction was taken up some five or six years ago, but for some reason was dropped. It was attempted to employ balance coils somewhat in the way Professor Ryan does, but the difficulty was in the winding of the coils about the field magnets. At the time I refer to, the amatures were smooth bodied. Armatures with slots of the Pacinotti type were considered to be of practically no value, and it was only by the application of a slotted core that balance coils operated successfully.

PROF. W. M. STINE:—I scarcely feel like discussing the paper, for as it stands it is so clearly written and the results are so evident that there seems to be very little ground left for discussion. However, it appears that under best conditions, it will no doubt prove very successful, but I am inclined to think that the boundary between success and failure is very narrow. I think that if the correcting winding is not very accurately placed, it will have a reverse effect as the author clearly indicates. I am inclined to think that this is a point that will cause quite a little difficulty at first. The exact balancing of the coils; putting the ring on the field properly may lead to some serious failures at first. It may be that the machines will be so thoroughly built that these difficulties will be obviated.

I am surprised that the author makes no mention of the work of Sayers in England. I would say that the work of Sayers is to put reactive coils on the armature instead of on the fields. This device is built and is on the market in active operation. I notice that a paper has recently been read before the Institution of Electrical Engineers in London in which Sayers gives data of two years' test of this device. I am unusually interested in this device of Prof. Ryan's in placing it alongside that of Sayers.

MR. C. E. KAMMEYER:—I would like to ask whether or not the experimental machines referred to have ever been run at their rated output for any length of time. I think that machines of this type or any type should be able to run 24 hours continuously at full load if necessary, without seriously heating, and I am very much interested to know if such tests have ever been made on these machines.

PROFESSOR FORTENBAUGH:—Regarding the question as to whether there has been any test made to this extent I can say this, that I do know of this first machine having been run for 10 or 12 hours at a time, but not for 24. No mention is made of the rise of temperature after having run for two or three hours. In a large machine it will take at least 5 or 6 hours before it becomes thoroughly heated.

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MR. L. L. SUMMERS:—I believe that some of the companies have adopted a standard of four or five hours for a test run. My information comes from one of their testing experts, who has tested some of the largest of their machines. I think that for practical purposes a run of four or five hours will usually be sufficient for the machines to attain their highest temperature. I think that the question of armature reaction is of great importance in machines for special work. I had occasion to change the secondary winding of a dynamotor for the purpose of lowering the voltage, and upon figuring out the cross magnetization I came to the conclusion that I could decrease the length of the primary winding about 16 per cent., and instead of its increasing the speed of the machine as one would suppose it would, the speed would remain constant, showing the effect of armature reaction may have in this class of machinery.

PROFESSOR FORTENBAUGH:—The paper written by Professor Ryan seems to be a presentation of results rather than a sketch of the possibilities of the device, and from these results I think no other conclusion can be drawn, than that it is a practical success. Now, can it be built satisfactorily and cheaply? These balancing coils are now made so that they can be put on with no injury to themselves or to the machine under ordinary conditions, and the effect that these coils have on the armature reaction more than compensates for any complications that may arise by their use. There seems to be some doubt as to whether or not they increase the cost of the machine. Professor Ryan assures us that the increased cost, due to the coils, is more than counterbalanced by the saving of materials, and therefore I do not see why it should not be a commercial success.

I wrote Professor Ryan, asking him about the increased cost, and though I have received a letter from him since, he has said nothing about this, and I took it for granted that he thought the question sufficiently answered in the last paragraph of the paper. And furthermore if there is any slight increase in the cost of manufacturing this machine, we know that the efficiency at all loads is very much increased, and therefore we have a continual saving in this way which more than covers the extra expense of constructing it.

PROFESSOR W. M. STINE:—I would like to ask whether the external compound or series coils were effected on the Thomson-Houston machines?

MR. B. J. ARNOLD:—We always regarded the compound winding as a very essential part of the machine.

MR. A. V. ABBOTT:—I have never had the time, I regret to say, to make an actual test of this class of machines, but in a southern station where we had three Edison 80 H. P. machines, and two Thomson-Houston machines, so far as actual running conditions on the railway were concerned, we could run the Thomson-Houston without moving the brushes at all, where we

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could not do so with the Edison. When all the Edison machines were running at full load, for some reason or other the load might be suddenly thrown off and they would spark considerably, so that the attendant would be compelled to keep his eye on the commutators, whereas with the Thomson-Houston machines there is no need of doing anything to the brushes at all.

Mr. Kammeyer:—While the authors seem to have solved the problem of preventing armature reaction, and thereby doing away with sparking at the brushes, I do not believe they have given due credit to other dynamo builders. I fully believe that machines are being built to-day without balancing coils that will not spark when running at full load or even at overload, and that do not require the shifting of brushes under varying loads. As to the higher efficiency at small loads, that I believe is a very important point, but I doubt very much that the increased cost of building machines of this kind will be compensated for by the slight increase in output. I do not believe that crowding too much machinery into a small space is a good thing. I believe in having plenty of room in your machine, and it will then run much cooler, other conditions being equal. I believe that the authors refer to one case where they have tried to get too much out of the machine. This caused me to ask how long any of these machines had been run, and I believe that if they had run them for ten or twelve hours at a time under full load, they would have found that the heat increased very rapidly.

Mr. Cochrane:—I would like to ask if the balancing coils are wound in place by hand or not. It seems to me that if they are wound by hand, the cost would be somewhat excessive.

Professor Fortenbaugh:—These balancing coils are wound in place by hand. You seem to have the impression that this machine, when fitted with these coils, costs more than a machine constructed in the ordinary way, and the authors state that it does not. Regarding the originality or the credit for this device being given to Professor Ryan, I would say that Professor Ryan and Mr. Thompson do not claim that their idea is an original one. If you will refer to the London *Electrician* (vol. xxxi) you will find a device that is suggested by Fischer-Hinnen, quite similar to the one used by the authors. Mr. Sayers' device, with a number of others, has also been tried with apparent success. The ordinary machine, as now built, will admit of working perfectly satisfactory from no load to full load, but I know that this device of Professor Ryan's will give better satisfaction at overload, and it will more than double its load without any appreciable sparking.

Prof. Stine:—At the time this was being developed, the Thomson-Houston type of machine was pretty thoroughly tested at Cornell, and I should be very glad to hear of the experience and experiments and whether they found the reaction winding efficient, and controlled the sparking, also whether they ever

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attempted to short-circuit that or whether they left it on open circuit.

MR. O. S. LYFORD, JR.:—I happened to be at Cornell at the time when this first machine was designed, and in fact, made the drawings under Professor Ryan's direction. Since then I have kept track of the subject as much as possible, and in connection with my work have made a number of interesting observations. There are a number of machines on the market to-day which will work under all conditions of load with practically no sparking. The only advantage of this construction proposed by Professor Ryan is that it preserves the point of commutation, but there are other ways of accomplishing the same results with equal success, and I think with equal efficiency. My experience has been principally with the internal pole type of machine, and I have seen machines of this type working from no load to 50 per cent. overload without sparking, without shifting the line of commutation, and with the use of copper brushes. One of the last things Professor Ryan says in the paper is that "The M. M. F. of the armature ampere-turns may never exceed the M. M. F. impressed by the field between the pole faces." Professor S. P. Thompson's statement in reference to the same subject is that the ampere-turns of the armature circuit can not be greater than the ampere-turns necessary to produce the field in the air spaces. Contrary to either statement I have found in some instances that the armature ampere-turns may be double the field turns necessary for the air-gap. This may be due to the additional effect of the compound winding. The only thing about this proposed construction, as I have said before, is that it places the remedy at the exact point where the trouble exists. Perhaps one particular use for this construction will be where it is required to have machines work with full load but with widely varying speed. In some of the curves he shows that the voltage can be varied from 112 to 48 by varying the strength of the field, and yet the commutation remain practically sparkless. In the same manner it should be possible to vary the speed with constant voltage. This is a thing that is impossible with the old construction of machines. The possible variation ordinarily is 25 per cent. where he makes it 50 per cent. or more. This should make this style of machine well adapted for motors operating machine tools.

MR. LUDWIG GUTMANN:—I believe, that Professor Ryan has taken a stand which he can easily defend. One of the speakers said that any of the present manufacturers can conform to the specifications, viz., to furnish a dynamo to operate sparkless from no load to full load, or even overload. If this method of Professor Ryan was adopted, the air-space could be considerably reduced and the capacity of the dynamo increased. It is certainly true that most manufacturers can furnish dynamos which will run sparkless over the normal range at the expense of a good deal of power and material, but I believe Professors Ryan's

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method admits of better utilization of the material put into the machine and with less internal waste. By his method the present machines can be increased in output, or new machines may be built smaller for the same output and with less amount of iron and copper.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, April 17th, 1895.

The 96th meeting of the INSTITUTE was held at 12 West Thirty-first Street this date, and was called to order by President Houston, at 8.15 P. M. Seventy members and guests were present.

THE PRESIDENT:—Gentlemen, before proceeding with the regular course of business, it is my sad duty, as President of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, to announce to you the sudden death of our Treasurer, Mr. George M. Phelps. There were few, if, indeed, any, of the members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS who were more closely identified with the growth and work of this institution than Mr. Phelps. He was one of our charter members. He was elected a Manager in 1885, and had, since that time, been continuously a member of Council. He was elected Treasurer of the INSTITUTE in May, 1887, and had held that office continuously until the time of his death. These facts, are in themselves, evidences of the very high esteem in which our late Treasurer was held by the INSTITUTE. My acquaintance with Mr. Phelps commenced with the beginning of our INSTITUTE in 1884. I was first brought into contact with him at the International Electrical Exhibition, held in Philadelphia, under the auspices of the Franklin Institute. I learned then to respect the gentleman for his many good qualities. While I have not had that intimate friendship and acquaintance with him, which some of you have had, yet I wish to testify to the many excellent traits of character he possessed, especially to the excellent and faithful services he has rendered me, as your presiding officer, during the two years in which I have had the honor to be connected with the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS as its President.

Genius is a rare gift, and if it be true that genius consists in the possession by one individual of some trait of character, not possessed in general by mankind, then I take it that the faculty called common sense is one of the most marked attributes

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of genius since it is so very uncommon. Our late Treasurer, in my judgment, possessed an uncommon amount of that very uncommon trait, common sense. This was particularly noted in the council chamber, where we were always sure, if a knotty question arose, that needed a clear understanding and calm judgment, that we would get the best of advice from our late Treasurer.

I join with you in mourning over his sudden death. Death is at best an unwelcome visitor. But nature is merciful to us at least in this respect, that when death comes with old age, she kindly tempers our departure so that when we die, we practically have been dying for many years. But when a man is struck down in the vigor of his manhood, right at the height of his usefulness, as was our late Treasurer, then death indeed becomes a sad visitor.

I will not attempt to speak of the social characteristics of Mr. Phelps or of those traits which so distinguished him as a man; for, as I have said, you know them well. He was a dignified gentleman, and if we add, of the old school, it is certainly not to his detriment. He was a delightful companion, a sympathetic friend, a faithful brother, a loving father and husband, and I think that it can be said of him that he filled the measure of a useful life, in that he so lived that the world was better and brighter and happier that he had lived in it.

I felt that it would not be proper for me to open the meeting of the INSTITUTE without making some brief reference to the death of our Treasurer, and I trust that you will pardon the very imperfect manner in which I have made it.

MR. HAMMER:—In connection with this announcement permit me to read the following communication from the Council:

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, April 17th, 1895.

The Council of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, desiring to express its sense of the loss to the INSTITUTE in the death of George May Phelps; at its meeting held Wednesday afternoon, April 17th 1895, at the INSTITUTE headquarters appointed a special committee of three to draft suitable resolutions which the undersigned as committee herewith respectfully present.

Resolved: That in the death of George May Phelps, the Council has suffered the loss of an energetic, faithful and capable member, and the INSTITUTE a most efficient officer; one who was constantly striving to uphold the standard of its work, and one who was ever watchful of its welfare. In his disinterested efforts to serve the INSTITUTE, he brought to bear upon its deliberations, his keen perceptions, intellectual ability, and eminent force of character.

Resolved: That a copy of this resolution be suitably engrossed and framed, and presented to Mrs. George Wallace Graham, his daughter, and the sole surviving member of his family.

WILLIAM J. HAMMER.
(Signed) JAMES HAMBLET.
RALPH W. POPE.

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MR. A. E. KENNELLY:—Mr. President, I beg to move that the INSTITUTE hereby cordially and unanimously adopts the resolution which has been placed before it.

PROF. ANTHONY:—Mr. President, I second that motion.

THE PRESIDENT:—It is moved and seconded as you have heard. Those in favor of the motion, will signify their assent by rising.

[The motion was unanimously carried.]

THE PRESIDENT:—The Secretary will now read the minutes of the last meeting.

The Secretary read the minutes of the ninety-fifth meeting of the INSTITUTE held March 20th, 1895, which were approved.

THE SECRETARY:—At the Council meeting held this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
BALDWIN, JAS. C. T.	Superintendent Chicago Telephone Co., 203 Washington St.; residence, 1350 Washington Boulevard, Chicago, Ill.	A. V. Abbott. S. J. Larned. A. S. Hibbard.
CABOT, FRANCIS ELLIOTT	Supt. of Inspection and Electrician, Boston Board of Fire Underwriters, 55 Kilby St.; residence, East Milton, Mass.	E. J. Houston. W. J. Jenks. A. E. Kennelly.
FORTENBAUGH, S. B.	Asst. Prof. of Electrical Engineering, University of Wisconsin, Madison, Wis.	D. C. Jackson. F. R. Jones. Harris J. Ryan.
HARRIS, W. C., JR.	Electrician, Harris & Williamson, Birmingham, Ala.	Geo. H. Harris. S. R. Gross. Richard Varley, Jr.
JONES, G. H.	Agent, General Electric Co., Casilla 18 D Santiago; residence, Iquiqui, Chili.	J. W. Kirkland. John B. Blood. Chas. P. Steinmetz.
LEBLANC, CHARLES	Chief Engineer Railway Department, Thomson-Houston Co., 27 Rue de Londres, Paris, France.	F. J. Sprague. S. D. Greene. D. C. Jackson.
LINDSAY, WM. E.	Chief Engineer and Electrician, Swift & Co., National Stock Yards, East St. Louis, Ill.	Fred'k Bedell. Ernest Merritt. Harris J. Ryan.
NUNN, PAUL N.	Consulting Engineer, San Miguel Cons. Gold Mining Co., Telluride, Colo.	C. P. Steinmetz. A. Jay Wurts. Chas. S. Bradley.
WINSLOW, GEORGE HERBERT	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.	A. Jay Wurts. L. B. Stillwell. Chas. F. Scott.

Total, 9.

The following associate members were transferred to full membership, their applications having been approved by the Board of Examiners, March 12th, 1895.

SCHMID, ALBERT	Superintendent, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.
DODGE, OMENZO G.	Professor of Mathematics, United States Navy, Washington, D. C.
CARUS-WILSON, CHARLES ASHLEY	Professor of Electrical Engineering, McGill University, Montreal, Can.
LIGHTHIPE, JAMES A.	District Engineer, General Electric Co., San Francisco, Cal.

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CHILDS, ARTHUR EDWARD	Electrical Engineer, Westinghouse Electric and Mfg. Co., Philadelphia, Pa.
WARING, JOHN	Warner Electric Co., Ovid, N. Y.
PUFFER, W. L.	Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston, Mass.
RYAN, H. J.	Professor of Electrical Engineering, Cornell University, Ithaca, N. Y,

Total, 8.

At the same meeting Mr. George A. Hamilton was elected Treasurer to serve for the unexpired term of the late Treasurer, George M. Phelps.

THE PRESIDENT:—The first business of the meeting is the reading of the paper by Mr. Kennelly and myself on "Resonance in Alternating Current Lines." Will Mr. Kennelly read the paper?

[The following paper was then read by Mr. Kennelly.]

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A paper presented at the Ninety-sixth Meeting of the American Institute of Electrical Engineers, New York, President Houston in the Chair, and Chicago, Manager A. S. Hibbard in the Chair, April 17th, 1895.

RESONANCE IN ALTERNATING CURRENT LINES.

BY EDWIN J. HOUSTON AND A. E. KENNELLY.

In a paper, by one of the authors, on the subject of "Impedance," read before the INSTITUTE[1] on the 18th April, 1893, the drop of pressure in conductors carrying alternating currents and assumed to possess no capacity, was considered. In the present paper, it is proposed to consider the conditions of current and pressure in an alternating current circuit, possessing electrostatic capacity as well as inductance, resistance, and leakage.

The objects of the present paper are, therefore:

(1) To present the formula expressing the variation of electric current and pressure in an alternating current circuit under the most general conditions, and in its simplest form.

(2) To present calculations for the pressure and current in any alternating current circuit, by a graphical method.

(3) To investigate the effects of static capacity in an alternating current circuit.

(4) To investigate the effects of capacity and inductance on the delivery of energy at the distant end of a circuit.

In Fig. 1, let A B, be a length of $L = (L_1 + L_2)$ miles, or kilometres, of conducting circuit, supplied at A, with an E. M. F. of E volts, and connected to any desired apparatus at B. First assuming the line to be grounded at B, let E, be the pressure in volts, and I, the current strength in amperes entering the line at A. If the E. M. F. is alternating, the values of E and I, will be their effective values, such as are indicated by properly constructed voltmeters and ammeters. If the E. M. F. is continuous,

1. TRANSACTIONS, vol. X, p. 175.

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the values of E and I, will be their ordinary numerical values. If the E. M. F. is alternating sinusoidally, E and I, will possess not only numerical magnitudes, but also direction in a plane. Let e, be the E. M. F. in volts, and i, the current strength in amperes at B, the receiving end of the line. When B, is grounded, we must have $e = 0$, and when B is insulated, $i = 0$. At any intermediate position C, in the line, distant L_1, miles or kilometres from A, and $L_2 = L - L_1$ from B, let the E. M. F. be $\boldsymbol{e}$, and the current strength $\boldsymbol{i}$.

In any circuit, whether alternating or continuous, we assume that the pressure and current are known at one end of the line at least; that is to say, we know either E and I, or e and i. It is, therefore, required to determine $\boldsymbol{e}$, and $\boldsymbol{i}$, at all intermediate distances under the given conditions.

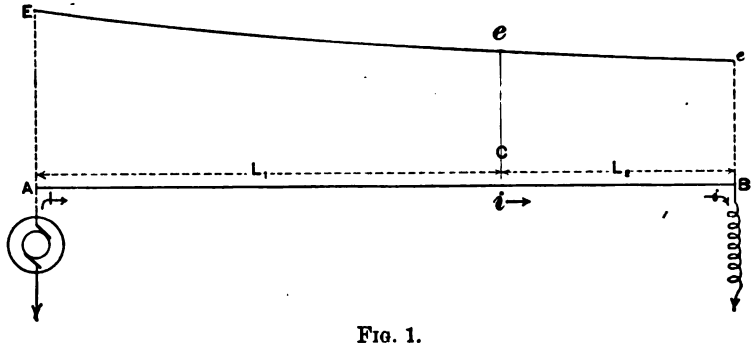

FIG. 1.

Under ordinary conditions we have to supply at the distant end of the circuit, a steady pressure of e volts, to a transformer, motor, or other translating device, and, when the load is known, i, is usually known.

In practice, lines are not usually grounded, a metallic circuit being employed. It is probably simpler, however, to discuss the phenomena as they occur on ground-return circuits, and then to bring metallic circuits within the treatment, by regarding them as composed of two parallel, grounded circuits, with the ground connection at the center of the generating E. M. F. at A, and at the center of the translating device at B. Each line will then have half the E. M. F. and half the impedance of the transmitter and receiver. (See Appendix III).

Regarding now the line A B, as being perfectly insulated be-

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tween A and B, and as operated by a continuous E. M. F., we know that the pressure at any point is equal to the terminal pressure, with the addition or subtraction of the drop, according to the terminal considered, or

$$e = E - I L_1 r = e + i L_2 r \qquad \text{volts} \qquad (1)$$

and

$$i = I = i \qquad \text{amperes} \qquad (2)$$

where r, is the resistance of the conductor in ohms per mile or kilometre. The above simple relations between pressure, current, and distance, in a continuous current circuit, undergo comparatively simple variations in an alternating current circuit. Suppose an alternating E. M. F., E, of the sinusoidal type, and of angular velocity $\omega = 2\pi n$, n being the frequency, be employed on the line at A, with a current I, which may or may not be in phase with E. The line may possess an inductance of l henrys per mile or kilometre, a capacity of c farads per mile or kilometre, and a leakage conductance (the reciprocal of insulation) of g mhos per mile or kilometre. Then formula (1) becomes, in the case where all these quantities are present.

$$e = E \cosh L_1 z - I y \sinh L_1 z = e \cosh L_2 z + iy \sinh L_2 z. \quad (3)$$

$$i = I \cosh L_1 z - \frac{E}{y} \sinh L_1 z = i \cosh L_2 z + \frac{e}{y} \sinh L_2 z. \quad (4)$$

It will be seen that formula (3) differs from formula (1) in that the pressures E and e, are multiplied by the hyperbolic cosine of the quantity $L_1 z$, or $L_2 z$, according to the end of the line considered, while the current strengths I and i, are multiplied by the hyperbolic sines of the same quantity, and also by the quantity y.

In other words, the pressure at any point on the line, instead of being equal to the pressure at some other point of reference, plus or minus the drop between them, is equal to that reference pressure multiplied by the hyperbolic cosine of a function of the intervening distance, plus or minus a drop $Iy \sinh Lz$, which is also a function of the intervening distance, and these two quantities are not added numerically but geometrically.

Formula (4) is a more complex form of formula (2).

The quantities y and z, in formulas (3) and (4), depend on the impedances of the conductor and of the dielectric. The impedance of the conductor may be graphically represented as follows: Let the line r (Fig. 2), represent to scale, the resistance of the conductor per mile (or kilometre), and let $l\ \omega$, be the conductor

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reactance per mile, or the product of the angular velocity of the E.M.F. and the inductance in henrys per mile. Then the vector sum will be $(r + j\,l\,\omega)$ where $j = \sqrt{-1}$, will be the conductor impedance, shown by the dotted line C. I., and hereafter contracted C. I., expressed in ohms per mile at the angle α.

The impedance per mile of the dielectric has next to be found. Here we have a capacity in parallel with a leakage. The joint admittance of these quantities will be the sum of their separate admittances $g + j\,c\,\omega$, Fig 3. The length of the line g, representing the leakage conductance per mile in mhos, and $c\,\omega$, the dielectric-susceptance per mile, obtained by multiplying the capacity in farads per mile by the angular velocity ω. Then the line D. A. will

FIG. 2.

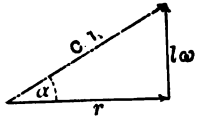


FIG. 3.

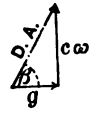
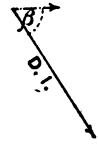


FIG. 4.



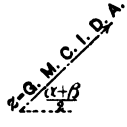


FIG. 5.

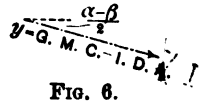


FIG. 6.

be the dielectric-admittance, hereafter contracted D. A., in mhos per mile, at the angle β. The dielectric-impedance D. I. will be the reciprocal of this admittance at the same angle $-\beta$, but negative, or below the line, as represented in Fig. 4.

The quantity z, is the geometric mean of the conductor impedance and the dielectric admittance, or

$z = \sqrt{C.I. \times D.A.}$, in the most general case a vector at an angle $\frac{\alpha + \beta}{2}$ as shown in Fig. 5. This quantity z, will hereafter be described as the mean C. I. D. A.; *i.e.* the geometrical mean of the conductor-impedance and the dielectric-admittance.

$y = \sqrt{C.I. \times D.I.}$, in the most general case, a vector at an

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angle $\frac{\alpha - \beta}{2}$, as shown in Fig. 6. This quantity y, will hereafter be described as the M. C. D. I. (geometrical mean of conductor and dielectric impedances). When the line is very long, the apparent resistance of the line from the sending end is y, so that the current strength entering the line will be $I = \frac{E}{y}$ amperes.

To illustrate, suppose a line whose conductor has a resistance of 2 ohms per mile, and an inductance of 20 millihenrys per mile, a perfect insulation ($g = 0$), and a capacity of half a microfarad per mile ($c = 0.5 \times 10^{-6}$). Let $\omega = 2000$, corresponding to a frequency $n = 318.3$ then,

$$l\,\omega = 0.020 \times 2000 = 40 \text{ ohms, and } c\,\omega = 10^{-3} = \frac{1}{1000} \text{ mho,}$$

then the conductor impedance, C. I. $= 40.05 \underline{/87^\circ\ 08'}$ ohms. The dielectric-admittance D. A. $= 10^{-3} \underline{/90^\circ}$ mho. The dielectric-impedance D. I. $= 1000 \overline{\backslash\ 90^\circ}$ ohms.

Then $z =$ M. C. I. D. A. $= \sqrt{0.04005 \underline{/177^\circ\ 08'}} = 0.2001 \underline{/88^\circ\ 34'}$.

$$y = \text{M.C.D.I.} = \sqrt{40.05 \times 1000 \underline{/2^\circ\ 52'}} = 200.1 \underline{/1^\circ\ 26'} \text{ ohms.}$$

The quantities $L_1\,z$ and $L_2\,z$, are prolongations of z; *i.e.*, vectors obtained by multiplying z, by L_1 and L_2 and setting off the product at the angle of z, in this case 88° 34′.

In order to determine e and i, we require to find the hyperbolic sine and cosine of the quantities $L_1\,z$ and $L_2\,z$. If $L_1\,z$ and $L_2\,z$, were mere numerical magnitudes, their hyperbolic sines and cosines could be determined from tables of those functions, but since $L_1\,z$ and $L_2\,z$, are vectors whose angle is $\frac{\alpha + \beta}{2}$, the hyperbolic sines and cosines are vectors and are tedious to compute. This labor can be avoided by the use of Plate I, which will give by inspection[1], the value of any hyperbolic sine and cosine within a certain range of magnitude, sufficient for most practical purposes.

When the plate is employed to determine hyperbolic cosines, it is held so that the letters R, appear in their correct position to the observer. To determine hyperbolic sines, the plate is held at right angles to this position.

If we have a point p, Fig. 7, situated in a plane, and we know its rectangular coordinates x and y, we may readily determine its polar coordinates r and θ, by calculation. Thus, if $x = 1$

1. Plate I, on an enlarged scale, may be obtained from the Secretary.

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and $y = 1$, $r = 1{,}414$ and $\theta = 45°$. We may either transform the coordinates by computation in each case, or we may carry out the process graphically. This could be done by drawing lines parallel to x and y at suitable distances apart, intersecting everywhere at right angles, and marking off from the point $x = 0$, $y = 0$, as center, a series of concentric circles, and radii intersecting all these circles at successive angular distances at right angles. We could then find directly from the diagram, by inspection, the polar coordinates of any point whose rectangular coordinates are given.

Plate I is intended for the purpose of giving by inspection the polar coordinates of a vector point, representing the hyper-

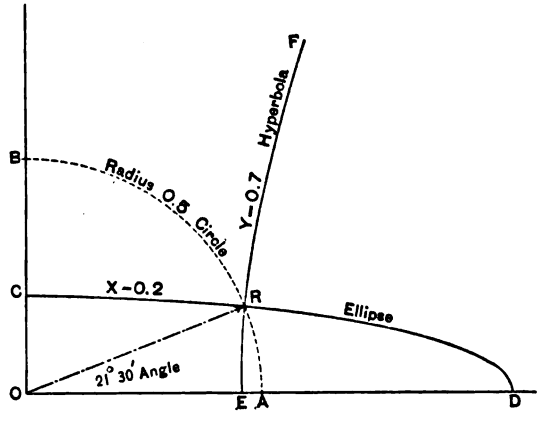

FIG 7 —Determination of the Hyperbolic Cosine of the Plane Vector whose coordinates are $X = 0\ 2$ and $Y = 0.7$- Result $0.5\ \underline{/21°15'}$.

bolic sine or cosine of a given vector, whose rectangular coordinates x and y are known. A series of ellipses represent values of x, and a series of hyperbolas, everywhere intersecting the ellipses at right angles, represent the values of y. At the intersection of any ellipse value of x, with the hyperbola value of y, will be the radius and angle, *i. e.*. the polar coordinates, of the hyperbolic sine or cosine, according to the direction in which the plate is held by the observer.

If, for example, we take the coordinates x = 0.2 and Y = 0.7, and enter the plate for hyperbolic cosines, we will find, as in Fig 7, that starting from the horizontal line 00, or the

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major axis of the ellipses at the right hand extremity, and counting Y, counter-clockwise, we find a hyperbola E R F, Fig. 7. This hyperbola is marked Y = 0.7. We then find the ellipse X = 0.2, C R D, and, at the intersection of these two lines will be the point whose polar coordinates give the hyperbolic cosine of the vector sought; namely R = 0.5, $\underline{/21° 15'}$, for R, lies on the circle of radius 0.5, at an angle, counted counter-clock-wise from O D, of approximately 21° 15′.

Turning Plate I through 90°, and again starting in this position, from the horizontal line 00, or the line of minor axes of the ellipses, we enter the plate for the hyperbolic sines of the same vector whose coordinates are X = 0.2 and Y = 0.7. We travel counter-clockwise from the right over the same ellipse as previously employed, and, at its intersection R, Fig. 8, with the hyperbola C R D, of Y = 0.7, we have the point whose polar coordinates give the hyperbolic sine required. This point lies between the circles R = 0.9 and R = 0.95, but nearer to the former and approximately at a radius R = 0.92 and an angle of approximately 84° 15′.

It will be observed that the ellipses are carried by successive steps of 0.05, as far as $x = 1.25$, so that the diagram is limited in the range of abscissas to this amount. Since, however, counting counter-clockwise, Y passes from 0, at the right hand side to 1, at the vertical, 2 at the left hand side, 3 at the lower vertical, and 4 at the starting point on the right hand, and so on, 1 to every 90°, or 4 per revolution around the diagram, any value of Y, can be accommodated.

The diagram, therefore, becomes practically, to a moderate degree of approximation, a graphic table of hyperbolic sines and cosines of any vector quantity contained between the rectangular coordinates $x = o$, Y, $= o$ and X = 1.25 Y = $\propto$. This range is sufficient for most problems that present themselves. Formulæ for computing hyperbolic sines and cosines beyond this range are given in Appendix I.

In order, however, to obtain this extended range of Y, by repeating its value in successive cycles of 4, it has been necessary to alter the numerical values of the ordinates Y. Since the natural period of revolution is 2π, or 6.2832, corresponding to Y = 4 in the diagram, each unit ordinate of the diagram corresponds to $\frac{2\pi}{4}$ or 1.5708. In entering the plate, the ordinate of the vector $L_1 z$.

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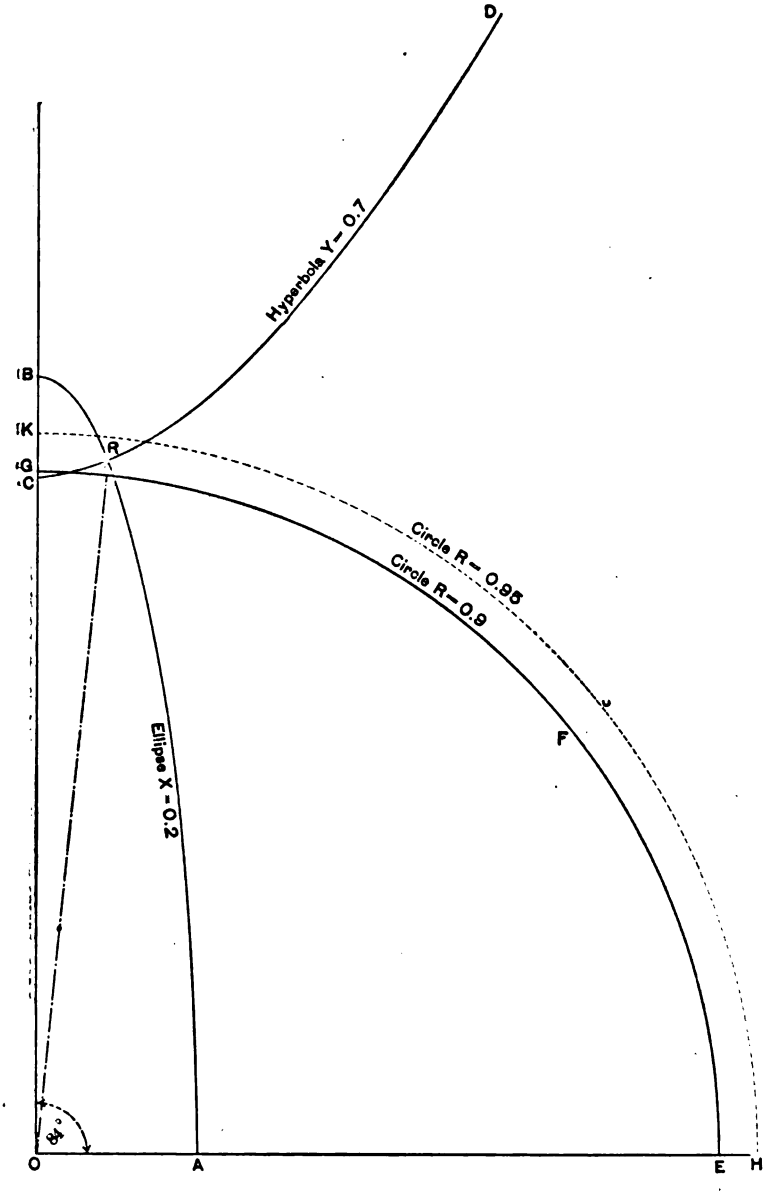

FIG. 8.—Determination of the Hyperbolic sine of the Plane Vector whose coordinates are $X = 0.2$ and $Y = 0.7$. Result $0.92 \underline{/84°15'}$

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or $L_2 z$ must be reduced in the ratio of 1 : 1.5708 or be multiplied by 0.6366. Thus, if $L_1 z$ happens to be 1.118 $\underline{/79°42'}$, we should find, as in Fig. 9, that $x = 0.2$ and $y = 1.1$. Multiplying y, by $\frac{2}{\pi}$ or 0.6366 we have (Fig. 9), $Y = 0.7$ and the hyperbolic sine and cosine of $x = 0.2$ and $Y = 0.7$ are already given in Figs. 7 and 8.

Plate II. affords a graphical means of accomplishing this reduction of the y coordinate by inspection. If, for example, we look for $y = 1.1$ along the axis of abscissas, we find $Y = 0.7$ as the corresponding ordinate. So that having found the abscissa x and ordinate y, corresponding to a given vector Lz, we find from Plate II. Y, the transformed value of y, and enter Plate I. with x and Y.

FIG. 9—Showing Analysis of Lz into Rectangular components to $Y = \frac{2y}{\pi}$.

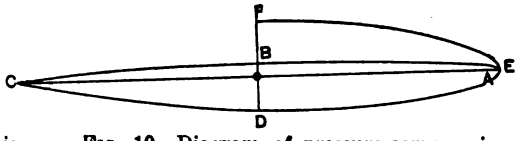

FIG. 10—Diagram of pressure commencing at insulated distant end $e = 1000 \underline{/0°}$

Returning to the general equations (3) and (4), if the distant end of the line B, be insulated, the current at B, is zero, or $i = 0$, and, therefore, $e = e \cosh L_2 z$, and $E = e \cosh Lz$. We only require therefore, to multiply the terminal E.M.F. at B, Fig. 1, by the hyperbolic cosine of the quantity $L_2 z$, to determine the pressure at any point along the line under these conditions.

Plate III., at A, represents a line 100 miles in length, for which the quantities r, l, c, g, ω, z and y, have already been determined above. If this line be considered as insulated at the distant end, on the left hand side of the plate, at 0 miles, and that a pressure of 1000 volts effective is maintained there by suitable adjustment of the sinusoidal E. M. F., generated at the sending end on the right of the diagram, 100 miles away, the pressure falls rap-

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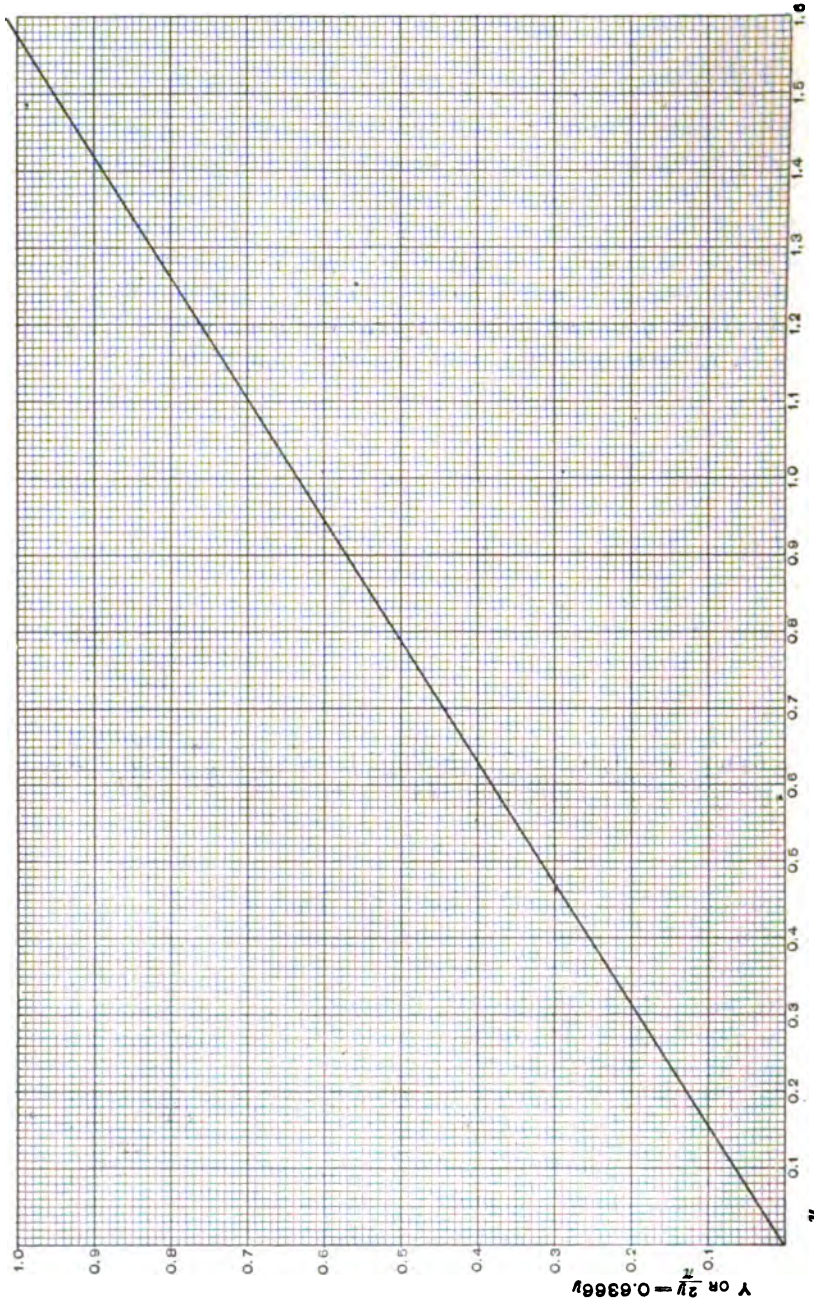

PLATE II. for transformation of y coordinates before entering Plate I.

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idly along the line marked *volts*, until it reaches a minimum of about 50 volts, eight miles from the receiving end. That is to say, if the line were only eight miles long, and a sinusoidal generator, of angular velocity 2000 radians per second, were inserted at this point, it would only be necessary to maintain a pressure of about 50 volts effective at the generator terminals, in order to maintain the pressure of 1000 volts effective at the insulated receiving end. At a distance of about 16 miles from the receiving end, the pressure again rises to 1000 volts, and continues to rise and fall rhythmically in stationary waves, the length of which is approximately 16 miles. It will be observed that the amplitude of the waves diminishes toward the sending end, while the average value of the pressure increases, so that if the length of the line were made sufficiently great, the pressure would rise very considerably at the sending end, and the waves or fluctuations in the pressure would practically disappear. In other words, cosh $L_2 z$, and sinh $L_2 z$, approach more and more nearly circular paths, since the ellipses of x, show less and less ellipticity as their numerical value increases.

Similarly by formula (4), for an insulated line, i, being equal to 0, we have $e = \frac{e}{y} \sinh L_2 z$, and the curve of *amperes* at A.

Plate III, represents the corresponding series of currents for this line. This current commences at 0, at the receiving end, where the line is open, and in the next eight miles increases to five amperes, falling again in the next eight miles to about 0.5 ampere, the wave length of the stationary waves, being also approximately 16 miles, and the current strength increases, steadily rising towards the sending end, the amplitude of the fluctuations diminishing.

The maxima, or crests of the current waves, coincide with the minima, or troughs, of the pressure waves, and *vice versa*. Moreover, the pressure and current coincide in phase at each pair of maxima and minima, so that the phase of the current and pressure coincide four times in each wave length.

Following the line of volts from 0, at the receiving end of the line, and taking the pressure of 1,000 volts there received as the standard of phase, the pressure advances steadily in phase as we approach the sending end. At eight miles from the receiving end, the phase is 90° or a quarter cycle, in advance; at 16 miles 180°; at 32 miles, 360°, or one complete cycle; at 94 miles, three

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complete cycles. In other words, if we consider the pressure at the sending end (100 miles) as at standard phase, the pressure at the receiving end will lag more than three complete cycles. Similarly, the current along the line of amperes will at 0 mile be of strength 0, but $\frac{1}{4}$ cycle ahead of the pressure, and will steadily advance in phase towards the sending end, and at 100 miles the current will be nearly $3\frac{1}{4}$ cycles ahead of the current at the receiving end.

Fig. 10 represents the phase variation of the pressure in the first 40 miles; O A, represents 1,000 volts, the received pressure at the insulated distant end, at standard phase; O B, represents 50 volts $\underline{/90°}$, the pressure about eight miles along the line; O C, 1000 volts $\underline{/180°}$ or negative, the pressure at about 16 miles; O D, 150 volts $\underline{/270°}$ or 150 $\overline{\backslash\ 90°}$ at about 24 miles; O E, 1,000 volts $\underline{/0°}$ at about 32 miles; O F, 220 volts $\underline{/90°}$, at about 40 miles.

From this diagram it is evident that a complete wave of pressure, having reference both to phase and amplitude, is about 32 miles in length, but in relation to amplitude only, is about 16 miles. Similar reasoning applies to the current strengths, and it is evident that at points along the line differing in distance by 16 miles, the current is in opposite directions at any and every instant.

Plate III, shows at B, the conditions of current and pressure existing along the line when the distant end is grounded at 0 miles, and a current of one ampere is caused to flow to ground. In this case the pressure is zero at the distant end, and formula (3) gives

$$e = i\,y \sinh L_2\,z;\ i = i \cosh L_2\,z, \text{ with } i = 1\ \underline{/0°} \text{ amperes.}$$

The curve *amperes* commences at 1, and at eight miles falls to about 0.05 ampere $\underline{/90°}$; the pressure at the same distance being about 200 volts $\underline{/90°}$, so that the pressure and current are in phase. They then fall out of phase, until at 16 miles, when they come into phase again at values

$$i = 1.0\ \underline{/180°} \text{ ampere approximately.}$$

$$e = 20\ \underline{/180°} \text{ volts approximately.}$$

The same general conditions are maintained throughout the line along the B, curves; namely, the pressure and current come into step every eight miles. The phase advances 90° for each eight miles toward the sending end. The wave length, in reference to amplitude alone, 16 miles, and in reference to both

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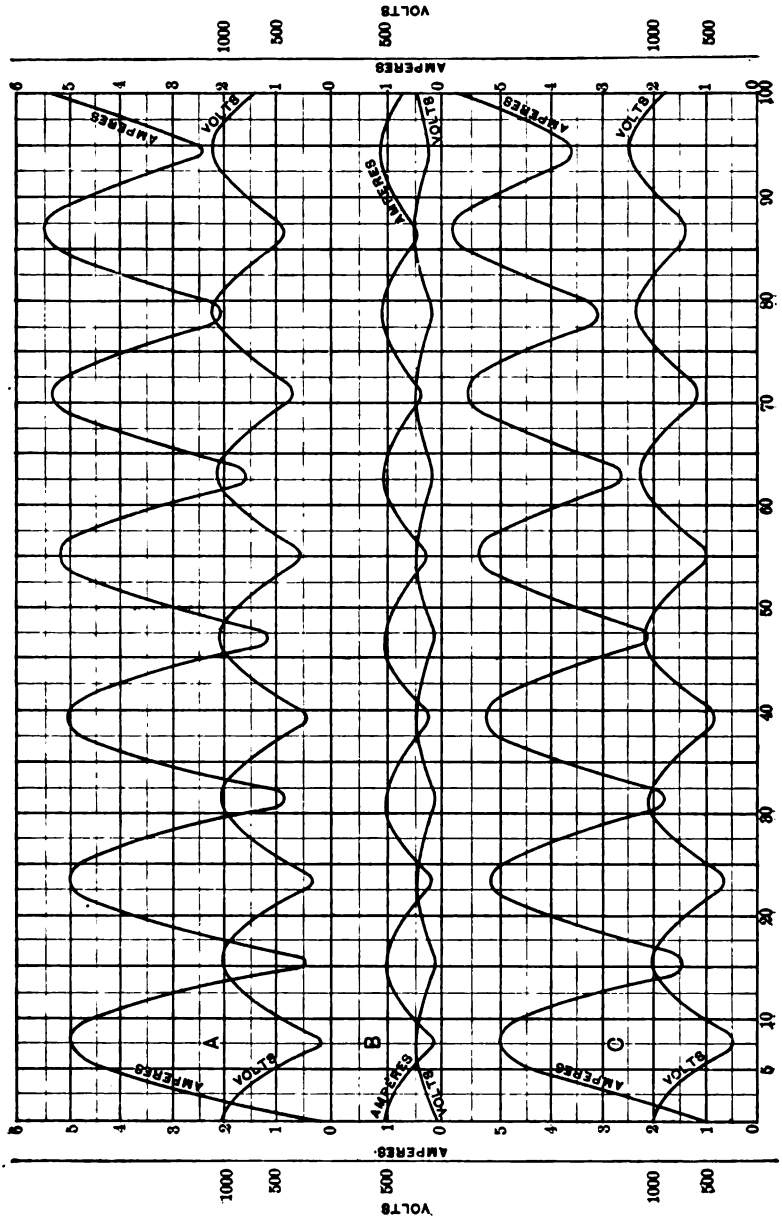

PLATE III.

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amplitude and phase 32 miles. The pressure and current, on the average, rise towards the sending end, while the fluctuations diminish in amplitude, or are damped out.

At 94.5 miles the current strength is 1.12 $\underline{/0°}$ amperes.

At 94.5 miles the pressure is 100 $\underline{/0°}$ volts,

making the apparent resistance of the line at this point approximately 90 ohms. The actual resistance of the line is, from the data assumed, $2 \times 94.5 = 189$ ohms, or, roughly, twice as much, so that the current strength delivered to the line is about twice as great as that which would be delivered by a continuous-current pressure of the same amount. The current delivered at the distant end (1 ampere) is nearly double that which the line would deliver if operated by the same continuous current pressure.

Plate III, shows, at C, the conditions which are maintained between the pressure and current when a current of one ampere is delivered at the distant end of the line, under a pressure of 1000 volts, representing a resistance of 1000 ohms, such as a number of incandescent lamps in series to ground at the distant end, and a total activity is delivered of 1000 watts. In this case formulas (3) and (4) become

$$\boldsymbol{e} = e \cosh L_2 z + iy \sinh L_2 z \text{ and } \boldsymbol{i} = i \cosh L_2 z + \frac{e}{y} \sinh L_2 z.$$

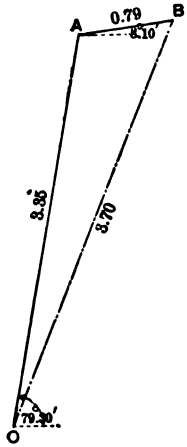

FIG. 11.—Vector Sum of Current Strengths.

The *volt* curve is here the vector sum of the two volt curves in A and B. The *ampere* curve is similarly the vector sum of the two ampere curves in A and B. In other words, if a certain current strength is necessary at any point in the line as at A, Plate III, to maintain a pressure of 1000 volts, with no current, while another current strength is necessary at the same point, as at B, Plate III., to maintain one ampere of delivery with no pressure; then the sum of these two currents, at C, or A + B, will deliver one ampere and also maintain 1000 volts at the distant end.

For example, Fig. 11 represents by the line O A, the current strength (3.35 $\underline{/79° 30'}$ amperes) in the wire at a distance of 35 miles from the receiving end, as at A, when 1000 volts and 0 amperes are delivered. The line A B, similarly represents the current strength (0.79 $\underline{/8° 10'}$ amperes), in the wire as at B, when

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0 volts and 1 ampere are delivered. The vector sum O B (3.70 $\underline{/68^\circ}$ amperes, represents the current strength at this point when 1000 volts and 1 ampere are delivered, as at C.

The general conditions C, being the sum of those at A and B, must be similar to those already traced, namely, the current and pressure are in phase at 0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 79, 86 and 94 miles approximately. They both rise in value, on the average, towards the sending end, with fluctuations diminishing in amplitude, the phase advances by 90°, every eight miles (nearly). At 94 miles, the pressure is 1220 volts $\underline{/0^\circ}$ and the current 3.6 $\underline{/0^\circ}$ amperes.

The apparent resistance of the line at this point is, therefore, 339 ohms, and the activity $1220 \times 3.6 = 4392$ watts. The continuous-current pressure, which would have been required at this point, to supply one ampere at the distant end, would be 1188 volts, and the activity 1188 watts. We, therefore, require nearly four times as much activity in this line at a frequency of 318.3 $\sim$ to yield the same power at 0 miles, as is required from a continuous source of E.M.F.

It is to be observed that while the pressure and current strength fluctuate in value as we pass along the line, the activity in the line does not fluctuate, but increases from 1000 watts at 0 miles, to 4392 watts at 94 miles. The rise is not uniform, being greater at the antinodes of current, or at the crests of the current waves, since the $i^2 r$ expenditure is greatest at those points; but the activity never ceases to rise as we advance toward the generator; for, it is evident that the activity in the line at any point, expressed by the co-directed product of pressure and current there existing, must, under the conditions here assumed, be equal to the terminal activity of 1000 watts, plus the total $i^2 r$ activity spent in the line up to the point considered.

The conditions of the line considered in Plate III. are not such as occur in practice. The frequency of 318.3 $\sim$ is only known in telephony, being six or eight times as great as would be employed for long-distance power transmission. The capacity of 0.5 microfarad per mile would only be obtained in large buried cables, and the inductance of 20 millihenrys per mile is several times greater than usually occurs.

Nevertheless, we have assumed these extreme conditions, partly for the purpose of obtaining conditions favorable to the devel-

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opment of resonance in the line, and partly to disprove the claim that has been made as to the economy offered by resonant lines for the transmission of power. It is evident that if a conductor, intentionally loaded with inductance and capacity so as to be resonant to the frequency employed, offered economical advantages for the transmission of power, there would, probably, be no great difficulty in artificially loading and adjusting the line resonance. For this reason the investigation of purely hypothetical conditions is not devoid of practical interest.

It is clear, from an examination of the conditions at B, as already described, that the resonance of the line enables a greater current strength to be supplied through the grounded distant end than would otherwise be possible. In other words, by heavily loading the line of 2 ohms per mile, with inductance and capacity until its inductance-reactance is 40 ohms per mile, and its capacity-reactance 1,000 ohms per mile, we can deliver, roughly, twice as much current to ground through the distant end, over any length between eight and 24 miles, as would be possible with an unloaded line. Under these circumstances, however, the current delivers no energy. In order that it may deliver energy, the pressure at the distant end must be raised. When this is done, as at C, the advantage, at first gained, by increasing the possible current strength, is soon more than lost by the additional expenditure of power in the line.

In any alternating-current circuit, if there is no loss of energy, by leakage and hysteresis, in the dielectric surrounding the conductor, that is to say, if the line is aerial, and is perfectly insulated, the activity delivered to the line at the sending end must be equal to the power delivered at the receiving end, plus that wasted in the line as $i^2 r$. Any method, therefore, of supplying a given number of volts and amperes at the distant end, which entails variation from the mean or average value of the current strength, *i.e.* any method which induces fluctuations in the current strength, must unduly increase the total expenditure of $i^2 r$, and entail either a greater loss in transmission, or a greater expenditure in copper, except where the current to be delivered is great, and its delivery pressure small, conditions opposed to long distance transmission. In the case represented at C, Plate III, the activity absorbed by the line is 4,392 watts at 94 miles, of which only 1,000 watts are delivered at the distant end, making a loss of 3,392 watts in the line, or an average loss of 36.1

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watts per mile, due entirely to $i^2 r$, and such as would be produced by a steady current of 4.25 amperes, the actual current fluctuating between 1 and 5.95 amperes. Continuous-current transmission, or alternating-current transmission at a low frequency, over the unloaded line, would have supplied 1,000 watts at a steady current of 1 ampere, and with a loss of only 188 watts.

Were it possible to make an alternating-current transformer, or an alternating-current motor, resonant; *i.e.*, if it were possible to tune sympathetically into resonance, not only the line, but also the energy translating device at the distant end, it might be possible to derive an advantage from the use of a loaded circuit, in spite of its greater $i^2 r$ loss. But an examination of the conditions of resonance shows, that where resonance exists, very little work is being done. A highly resonant condenser has its pressure and current in quadrature, and, generally, the mere existence of resonance implies an elastic reflection of energy with the minimum absorption. In other words, the conditions requisite for the maximum delivery of work to such a device, are inconsistent with the conditions requisite for its resonance.

While, therefore, in the case of a telephone circuit, it is possible that the current strength through the distant telephone, may, at some particular frequency, or range of frequencies, be increased, by loading the line, since the amount of work done in a telephone is small, yet when power has to be transmitted over a circuit on a large scale, it is wasteful to load the circuit.

And now as to the conditions favorable to the existence of marked resonance in an alternating-current circuit. When an alternating E. M. F., of E volts, is connected to a condenser through an inductant resistance of R ohms, the current strength in the circuit will attain the maximum value of $\frac{E}{R}$ amperes, when the inductance-reactance $l\,\omega$, is equal to the capacity-reactance $1/c\omega$. Similarly, a conducting line tends to vibrate electrically in sections such that their inductance-reactance and capacity-reactance are equal. The complete wave-length will be $2\,\pi \times$ the length of conductor in which these reactances are equal. With reference to amplitude only, the wave-length will be $\pi \times$ length of equal reactances, and the length in which the maximum amplitude of vibration is attained, $\frac{\pi}{2} \times$ length of equal reactances. For ex-

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ample, with the line considered in Plate III, the inductance-reactance is 40 ohms per mile, and the capacity-reactance 1,000 ohms per mile. In five miles, the inductance-reactance and capacity-reactance will both amount to 200 ohms, and the complete wave-length will, therefore, be $2\pi \times 5 = 31.42$ miles. As the resistance of the conductor becomes more prominent, relatively to the reactances, not only will the wave-length be interfered with, but the vibrations themselves will be damped and obscured. So that, if a line had very small resistance, and the reactances of short lengths of the line were equal and great, large and frequent vibrations would be set up with very little damping towards the sending end; or in other words, marked resonance would be developed.

Evidently, therefore, the controlling factor in the development of resonance is the vector z, or the geometrical mean C. I. D. A. If the length of z, is small, and its angle large, the vibrations will be large, but of small wave-length. If its angle be small, and its length great, the resonant vibrations will either be small or entirely absent.

When the angle of z is 45°,					the maximum possible dip in pressure		= 0 %	or maximum possible rise in pressure		0 %.
"	"	"	"	50°,	"	"	2.5 %	"	"	2.6 %.
"	"	"	"	60°,	"	"	23.4 %	"	"	30 %.
"	"	"	"	70°,	"	"	45 %	"	"	82 %.
"	"	"	"	80°,	"	"	63 %	"	"	270 %.
"	"	"	"	85°,	"	"	87 %	"	"	670 %.

Therefore, no fluctuating rise in pressure in an alternating-current circuit is possible, unless the angle of the mean C. I. D. A. is over 45°, and marked resonance is not to be expected until this angle is over 60°. The most favorable condition for development of resonant effects is when the line is either insulated at the distant end, or is grounded through a large impedance, the condition represented at A, Plate III., z, having in that instance an angle of 88° 34′, and the rise in pressure being about 1900 per cent. or the dip 95 per cent., at 8 miles.

When a well insulated conductor has negligible dielectric hysteresis, the angle of the mean C. I. D. A. must be over 45°, and, consequently, when the distant end is insulated, the pressure must rise along any such alternating-current circuit, unless the line is long, and, in case of marked resonance, it will rise and fall rhythmically. In practice, however, this rise must be very small.

For example, consider a uniphase circuit of two No. 8 A. W. G.

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copper wires (diameter 0.325″ or 0.825 cm.) supported on poles at an interaxial distance of two feet. The inductance of each wire in this metallic circuit will be 1.69 millihenrys per mile (3.38 millihenrys per double mile or loop-mile), and the capacity of each wire 0.0179 microfarad per mile (0.00895 microfarad per loop-mile). At the high commercial frequency of 133 $\sim$ or $\omega = 835.6$, the inductance-reactance will be 1.412 ohms per mile, and the capacity-reactance 66,840 ohms per mile. The length of line in which these two reactances would become equal is 217.6 miles, making the wave-length, in regard to amplitude, 683.6 miles, and in regard to both amplitude and phase, 1,367 miles. For this line z, the geometrical mean C. I. D. A., is 0.004745 $\underline{/79° \; 53' \; 30''}$, indicating by the preceding table, a maximum possible rise of nearly 270 per cent. If the loop were 336 miles long, the calculated rise in pressure is 250 per cent., with the distant end insulated, so that 1,000 volts at the generator would produce 3,500 volts between the insulated ends 336 miles away. In existing practice, however, a more reasonable length would be 10 miles, and over such a length, the rise of pressure would only be from 1,000 volts at the generator, to 1,001 volts at the insulated distant ends, a quite insignificant amount, and when even a small load is thrown on at the distant end, the drop in the line, due to that load, would neutralize and reverse this rise first produced.

With reference to subterranean conductors in practical use, the Ferranti mains may serve as an example. The particulars for these mains are given by Dr. Fleming in his interesting paper on "Some Effects of Alternating-Current Flow in Circuits having Capacity and Self-Induction," as follows: (see Appendix II) $r = 0.034$ ohm, $l = 0.2857$ millihenry, $c = 0.367$ microfarad, $n = 67 \sim$. The inductance-reactance is, therefore, 0.1203 ohms per mile, and the capacity-reactance, 6472 ohms per mile; so that the length in which these reactances are equal is 231.9 miles. The amplitude wave-length would, therefore, be nearly 729 miles.

Owing, however, to the very small inductance of this line, the angle of the mean C. I. D. A. is only 55° 53′, representing only a small rise of pressure under the most favorable conditions, and over such a great length as 360 miles, the resistance of the conductor would practically damp out all resonance. In a length of 11.49 miles, the maximum length tested by Dr. Fleming, the rise of pressure at no load should be nearly 0.3 per cent., or near-

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ly 30 volts in 10,000. Observations 13 and 14 of Table I., on p. 391 of his paper, show this rise, although other observations show a greater rise. The readings of the voltmeters are stated to have necessarily been subject to some little inaccuracy.

Formulas (3) and (4) are capable of including the effects of dielectric hysteresis when measurements of the same have been made; for, the effect of hysteresis in a dielectric, is to permit the expenditure of energy in it, as though leakage occurred across it, and the leakage conductor g, has only to be increased until $e^2 g$, is the total wasteful activity in watts in the dielectric per mile due to hysteresis and leakage combined.

The formulas are also applicable to triphase transmission when the proper inductance and capacity of the three conducting lines are employed. See Appendix III.

Formulas (3) and (4) are in the most general form and assume simpler forms in special cases. Thus if $l = o$ and $c = o$, we have the case of a leaky continuous-current circuit. In this case y and z, become numerical, instead of vector, quantities. Consequently sinh L z, and cosh L z, are numerical quantities, capable of being obtained from trigonometrical tables of these functions. The pressure in this case never rises towards the distant end of the line. When the distant end of the line is insulated, the pressure falls along a curve which is a simple catenary.

When $g = o$ and $c = o$, we have the case of an alternating-current circuit with negligible leakage and capacity. The formulas then become

(3) $e = E - I L_1 (r + j l \omega) = e + i L_2 (r + j l \omega)$.

(4) $i = I \qquad\qquad\qquad\qquad = i$

Here $(r + j l \omega)$, is the impedance of the conductor per mile, and the current strength remains the same throughout the line. As an example, suppose that the line consists of a pair of No. 0 A. W. G. aerial wires, each one mile long, at an interaxial distance of 2 feet, the frequency being 140 ∼. If a transformer be supplied at the distant end, with a pressure of 2000 volts at standard phase, and a current strength of $50 \overline{\backslash 10^\circ}$ amperes, required the pressure and current at the generator. The impedance factor for such a pair of wires is 3.08, and the angle whose secant is 3.08 is 71° 3′, so that the impedance per mile is $1.602 \underline{/71^\circ\ 3'}$ ohms. The pressure at the sending end on each line is, therefore, $1000 + 50 \overline{\backslash 10^\circ} \times 1.602 \underline{/71^\circ\ 3'} = 1000 + 80.1 \overline{\backslash 61^\circ\ 3'}$, and the vector sum of

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these is 1041.5 $\underline{/3° 52'}$. The E. M. F., at general terminals will therefore be 2083 volts $\underline{/3°52'}$. The current at the generator is $\underline{50° \backslash 10°}$ amperes.

Although, as we have seen, a sinusoidal E.M.F. at ordinary commercial frequencies, has very little power to produce resonant effects in ordinary transmission lines, yet, where prominent harmonics exist in the E.M.F. of the generator, we may expect, since the frequency of these harmonics is some odd multiple of the fundamental frequency, that they will be able to excite resonance when the fundamental practically fails to do so. It should be remembered, however, that in practice, the amplitude of the harmonics in an E.M.F. usually diminishes with the order, *i.e.*, the frequency of the harmonic, and, consequently, that although a high harmonic may be capable of developing powerful resonance in a line by reason of its frequency, yet by reason of its small initial amplitude the effect of such resonance on the total pressure will be necessarily reduced. It is possible, however, under special conditions, that an E.M.F., differing markedly from the sinusoidal type, may give rise to a considerable elevation in pressure at the distant end of a line, and this is an argument in favor of the sinusoidal type of E.M.F. wave in generators for long distance transmission.

We have not yet had the opportunity of verifying the rise in pressure, or resonant effects here described, in an actual alternating-current circuit. As already pointed out, a circuit in order to manifest such effects in marked degree should have considerable length, good insulation, low conductor resistance, large capacity, large inductance and a high frequency.

Through the courtesy of the Pennsylvania R. R. Co, through its Division Operator, Mr. W. F. Taylor, we were able to make some measurements of current strength and pressure over various lengths of telegraph circuits, both with continuous and alternating currents, employing with the latter a frequency of 125 ~. The resistance of a telegraph line is so large, relatively to its inductance and capacity, that at this frequency, the angle of the mean C. I. D. A. was only 54°, and, consequently, no marked resonant effects could be expected. There were, however, marked differences between the measurements with continuous and alternating currents. The results were in agreement with theory within the limits of uncertainty as to the magnitude of the inductance, capacity, and leakage of the lines.

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The effect of inductance in an alternating-current circuit, possessing negligible capacity, is to increase the drop in the conducting lines, without sensibly increasing the energy expended in the lines by a given current strength. Consequently, for any given activity supplied at the receiving end, at a certain pressure and current, the pressure at the generating end is raised above that which would be needed if the circuit could be operated by continuous currents. There is, therefore, a certain percentage of increased capacity in the generating plant, *i. e.*, an increased pressure for the same current strength, and the cost of the generating plant, therefore, tends to increase, owing to the inductance in the line, although the expenditure of energy in the line is not sensibly increased. The effect of capacity in the circuit is opposite to that of inductance, the pressure tending to rise at light loads along the line under their combined influence. At the same time the current, which is employed in charging and discharging the line, expends some energy in the conductor as i^2r. The cost of the plant is, therefore, reduced, as the pressure at the generator is reduced, but more power is expended in the conductor. The benefit to be derived in this manner from capacity in the line is, however, limited. Beyond a certain capacity-reactance, the loss of power in the line, owing to its resonance, costs more than the saving in generator capacity.

We conclude, therefore, from the foregoing, that in an alternating-current circuit:

(1) The combined effect of capacity and inductance is to produce a tendency to resonance.

(2) The tendency to resonance is favored by high frequency, high insulation, high inductance, high capacity, and high conductance.

(3) When the line is free at the distant end, the resonant effects are more pronounced at that end than at the generator.

(4) The determining factor for the production of resonance is the angle of the vector geometric mean C. I. D. A., and rapidly increases with the same.

(5) The complete wave-length in a resonant line is 2π times the length, in which the reactances of the inductance and the capacity are equal, the maximum difference of pressure or current strength being exhibited in one-quarter of this wave-length.

(6) When resonance occurs, the current and pressure in the circuit are not in phase except at their maximum and minimum values, *i. e.*, at the crests and troughs of the waves.

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(7) In resonant circuits, the lag of the pressure and current is 90° between any successive pair of maximum and minimum values.

(8) In ordinary lines, worked sinusoidally at ordinary frequencies, resonant effects are practically negligible.

(9) Prominent upper harmonics in the E. M. F. of the generator may sometimes give rise to appreciable resonant effects, although the resonance to the fundamental frequency may be inappreciable.

(10) A certain amount of capacity tends to increase the plant efficiency of the generator, and is, therefore, economical, but marked resonance in a line not only ceases to be economical, but is actually wasteful.

(11) Although, on a large scale, less energy can be delivered at the distant end of a powerfully resonant line, than on a non-resonant line, yet a greater current strength can in some cases be delivered over a powerfully resonant line.

Appendix I.

Useful Additional Formulas.

Vectorially, $\cosh(a + j\,b) = \cosh a \cos b + j \sinh a \sin b.$ (5)

" $\sinh(a + j\,b) = \sinh a \cos b + j \cosh a \sin b.$ (6)

Numerically, $\cosh(a + j\,b) = \sqrt{\cosh^2 a - \sin^2 b}.$ (7)

" $\sinh(a + j\,b) = \sqrt{\sinh^2 a - \sin^2 b}.$ (8)

The apparent resistance of a line A B, from the sending end A, when insulated at B, is $y \coth Lz$ ohms;

" grounded at B, is $y \tanh Lz$ ohms.

When L, is great, these converge towards y ohms.

The apparent resistance of a line A B, at the receiving end B, when grounded at B, and supplied with E. M. F. at A, is $y \sinh Lz$ ohms.

Example I. Required the hyperbolic cosine of the vector $1.118\ \underline{/79^\circ\ 42'}$ whose rectangular coordinates are $x = 0.2$ and $y = 1.1$,

$$\begin{aligned}
\text{by (5) } \cosh(0.2 + j\,1.1) &= \cosh 0.2 \times \cos 1.1 + j \sinh 0.2 \times \sin 1.1. \\
&= 1.0201 \times 0.4536 + j\ 0.2013 \times 0.8912. \\
&= 0.4627 + j\ 0.1794. \\
&= 0.4963\ \underline{/21^\circ\ 12'}.
\end{aligned}$$

Example II. Required the hyperbolic sine of the same vector

$$\begin{aligned}
\text{by (6) } \sinh(0.2 + j\,1.1) &= \sinh 0.2 \times \cos 1.1 + j \cosh 0.2 \times \sin 1.1. \\
&= 0.2013 \times 0.4536 + j\ 1.0201 \times 0.8912. \\
&= 0.09130 + j\ 3.909. \\
&= 0.9136\ \underline{/84^\circ\ 16'}.
\end{aligned}$$

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Appendix II.

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Appendix III.

I. In the case of a conducting line with ground-return circuit,
r is the res. in ohms per mile or kilometre of the conductor;
l " ind. in henrys " " " "
c " cap. to ground in farads " " "
E " effective E. M. F. at A, Fig. 1;
e " " " " B, Fig. 4.

II. In the case of a pair of conducting lines overhead, such as a uniphase aerial metallic circuit, consider each line separately, as being supplied with an effective E. M. F., E equal to half the effective E. M. F. of the generator, and an effective E. M. F., e, equal to half the effective E. M. F. e of the motor, transformer or translating device.

r = res. in ohms per mile of one wire;
l = ind. in henrys " " "
c = twice the capacity in farads per mile as measured between the wires;

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g = twice the conductance in mhos per mile measured between the wires.

When the conductors are buried, and each is surrounded with a metallic sheet, *e.g.*, a lead covered cable, c, is the capacity in farads per mile of each conductor to ground, and g, the conductance (and hysteretic coefficient) in mhos per mile of each conductor to ground.

III. In the case of three triphase conductors, consider each line as a single conductor operated to ground by $\frac{1}{\sqrt{3}} rd$, of the effective E. M. F. measured between wires at each end, with inductance and capacity as modified by the presence of the two other active lines.

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Discussion.

The President:—This paper is now open for discussion.

Mr. Charles S. Bradley:—Mr. President, this paper is a little in advance of my mathematics. I do not mean to cast any reflection upon Mr. Kennelly at all. It is often said that the papers are too mathematical. I do not think that is true in this case; I did not mean to insinuate that it was. It is made as plain, I think, as any such matter can be made, and I think great credit is due to you both for bringing out such a paper as this; for most people want to conceal and keep back for their own use all of these very valuable considerations. This is going to prove of great value to the alternating current work, I have no doubt; I am very certain of it. Although I cannot fully follow it, I can follow a portion of it, and I must say it is very instructive. The wave is a very striking thing, indeed, and I can say nothing except to praise the paper. I am unable to criticise it.

Dr. M. I. Pupin:—I venture to offer one or two remarks only on the paper. I think that it is a very useful thing to have certain mathematical functions, with which we are not very well acquainted, worked out numerically, and, if possible, reduced to graphical representation. This is especially true of the so-called hyperbolic sine and the cosine. These are the functions which puzzle us considerably in the problem of transmission of current along a line possessing appreciable distributed capacity, self-induction and resistance. The problem is an old problem, and used to engage the attention of some of the ablest physicists. As far as I know, the earliest authority on this problem is Prof. Kirchhoff, the same man who discovered spectrum analysis. He attacked the problem in 1857, and gave us what may be considered a complete solution of it. This paper of Prof. Kirchhoff is memorable for several reasons, and especially because in this paper it was stated for the first time in the history of electricity, so far as I know, that under certain conditions the velocity of propagation of an electric wave along a conducting wire is equal to the velocity of light. The result was predicted on the basis of the old theory.

The other reason why this paper is especially memorable is this: Prof. Kirchhoff attacked the problem as a physicist would do; namely, he considered in the first place a system in which there are a certain number of forces acting. Then he considered the physical constants of the system, and looked then for the fundamental relation between these forces and these constants. This is, in fact, the method which is general to all the physical problems, whether electrical, mechanical or any other kind. The fundamental relation which he obtained between the impressed electromotive forces and the physical constants of the line, that is self-induction, capacity and the resistance per unit length, is strikingly the same as the funda-

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mental relations which exist between the impressed forces on a flexible, suspended string and the physical constants of that string—namely, the weight per unit length, the tension, internal resistance, air resistance, etc. If the fundamental relation is the same in the two cases, it follows that the vibration of the string will follow exactly the same law as the transmission of an electric wave along the conductor, exactly the same; knowing one, we know the other. That is what I should call reasoning by analogy. It is not an analogy suggested by superficial observation, but it is an exact analogy. The employment of such analogies in our reasoning has been criticised lately on several occasions by people who ought to know better. Now, if we consider the motion of a string, we will get most of the results which the President and Mr. Kennelly have indicated in their very carefully worked out paper. We shall have what they choose to call resonance, when the energy which is communicated to the line reaches the end which is insulated, and is reflected, and the reflected wave and the incoming wave interfere and form stationary waves; and in a particular case, that is a case where we have no damping, of course, the returning wave would be almost as strong as the incoming wave, and we would have maxima and minima. The minima would be almost equal to zero. In this case they are not, because there is damping. Of course, it makes a difference whether the line is perfectly insulated or not. The damping factor, is the factor which consumes the energy of the wave. It is especially the ohmic resistance. The velocity of the wave, of course, as we all know, depends on the period of the wave. It is not the same for all periods. The wave is faster, the shorter its time of vibration; and the longer the time of vibration, the slower and the longer it is, and so on.

Now, Prof. Houston and Prof. Kennelly seem to be alarmed by the fact that certain people have made the very unscientific remark that transmission of energy can be effected more economically and better by a resonant line than by a line which is not resonant. That sounds to me like wanting to eat a cake and have it. The very fact that you have resonance means that you are accumulating something, that you are putting power upon a line without utilizing it. If you utilize it, of course then there is no cumulative effect, and there is no resonance. Mr. Kennelly has expressed that very well by saying that the resonance effects depend very much on the elastic reflection of the terminus of the line. Now in a great many cases we really do not care to transmit power in the ordinary sense of the word—that is, a large amount of power, over a long line. In these cases resonance, whether in this shape or in any other shape, offers considerable prospects. For instance, if we wish to transmit power to a certain point—a small amount of power—and we do not care what the efficiency of the transmission is, for in-

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stance, in telegraphy or telephony, we really do not care how much we put in—within certain limits, of course—provided we can get enough at the receiving end. This is a point worthy of our consideration, and I was rather disappointed when I saw that Professors Houston and Kennelly did not discuss this problem more fully than they did. But still, along the lines indicated by them, I think the subject could be very easily continued.

I think Professors Houston and Kennelly deserve great credit for the extremely careful way in which they have worked out the figure of Plate I, and I am glad to hear that anyone who wishes to have this plate can have it in enlarged form, because it really simplifies numerical calculations very much.

Mr. President, I take the pleasure of introducing to the INSTITUTE one of our fellow members, Dr. Webster of Clark University, who takes great interest in the INSTITUTE. I have no doubt that the members of the INSTITUTE would be pleased to hear what Dr. Webster has to say on the subject of this evening, especially since he is interested in a line of work which is within the region of our present discussion.

THE PRESIDENT:—I am sure we should all be pleased to hear from Dr. Webster.

DR. ARTHUR G. WEBSTER:—Mr. President and gentlemen of the INSTITUTE, I hardly expected to be called upon to address you on this my first appearance in this honorable body, in which, as my friend Dr. Pupin says, I take great interest, although I live somewhat out of the radius of New York.

I am extremely interested in this subject. I have thought about it for a good many years, and I have listened with great admiration to the reading of the paper, which I was fortunate enough to be able to look over before coming here. Some of my preconceived ideas have received a considerable shock in the course of that reading. Not being an engineer myself, and not knowing engineers as well as I wish I did, I had supposed that an engineer was an extremely busy man and that he was mostly occupied in doing practical things which brought him in a certain amount of very pleasant returns which are not open to people in my own position. But I came to the conclusion that there are engineers who delight in doing other things, who are willing to do work in arithmetic, which I may say for myself I find a terrible grind. If I have been fortunate enough to get certain experimental results and put them down in my notebook, when it comes to working the calculations over, I should prefer to send them several hundred miles rather than do it myself. But I have come to the conclusion that business is probably a little slack in Philadelphia. I have always had the impression that there were more hours in the day in Philadelphia than in New York. But I see that there must be a good many more hours in the day, and a good many more days in the week, and if I might take the liberty I should be glad to ask Mr. Ken-

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nelly privately how long it took him to draw that diagram. I was extremely interested in that part. I may say, in the first place that not having brought a dictionary with me I was a little at a loss for some of these terms ending in "ance," and if Mr. Kennelly's forbearance is as great as his admittance I will proceed to make a few remarks which I hope may be pertinent to the question. As I have said, it is extremely pleasant to find somebody who is willing to work out results which we may have had in formulas and to give us arithmetical results, with curves and pictures which it is pleasant to see and also to own. I am going to make a suggestion to Mr. Kennelly, which will entirely change the appearance of that plate, if he adopts it, although I do not expect he will, as the plate is engraved. As Dr. Pupin has said, this question is one of the most interesting in this department of mathematical physics, and has been so ever since it was taken up so long ago by Kirchhoff. All the results arrived at here to-night are probably in that paper. But it is very pleasant to think that when some eight or nine years ago I began reading the works of Mr. Oliver Heaviside, published in the London *Electrician*, before the advent of the omniscience which now rules in that quarter, I found that Mr. Heaviside had taken up the same problem and had come to the same results all by himself, and when he got all through he found that Prof. Kirchhoff had done the same thing twenty years before. That illustrates a disease peculiar to Englishmen, and others, of not reading other languages than their own, or perhaps not knowing that there are other languages than their own. I may say that whenever I want to know anything about alternating currents, before I understand it, I am obliged to sit down with my pen and go over the whole thing, as I did this afternoon—not understanding the terminology, I worked the thing out myself and presently I saw what was meant by all the terms. But I seldom spend very many weeks on a problem until I have looked over Mr. Oliver Heaviside's papers. Generally the solution is there. It is so in this case. It shows the advantage of being forewarned. Mr. Oliver Heaviside, of course, claimed some time ago from purely theoretical grounds when nobody was looking at him except Sir William Thomson, (I was looking at him too, but I will not name myself in this connection—I was one of the forty-nine who sent for a copy of his papers and got one), that the self-induction of wires was a very important factor in alternating current work.

I will now leave this and say that I enjoyed this part, and am glad that it has been done. It must have required an enormous amount of labor, and, after all, the conclusion seems to be that it *practically* does not amount to much. It has been a good exercise for Mr. Kennelly, different from what falls to the lot of engineers in general. As I say, Mr. Heaviside was one of the first to maintain from purely theoretical grounds that the induc-

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tance of wires was very important for telephony and other things. It had been claimed by the dominant school, the government school, in England, that self-inductance was hurtful and could not do any good. Mr. Heaviside said otherwise. If Mr. Heaviside's controverters had had their way, probably there never would have been any long-distance telephone lines in the world.

Another thing that struck me in this paper was the power of abbreviation. As I say, I am not used to those terms. Some of them I have used a good deal, but these words in "ance," and these vectorial methods struck me a little strangely. But I soon saw what they meant. However, the problem, as Dr. Pupin has said, is simply the problem of an elastic string moving in a viscous medium. If it is stretched the required amount and fastened at the end, it vibrates in nodes and loops; but if there is a viscous medium, there is a damping, and what occurs here in the wire and in a string moving in a viscous liquid is that the velocity of propagation is not the same as it would be without viscosity. Instead of having perfect interference and getting perfect nodes, which do not appear in the figure, the waves going and returning being damped, do not completely neutralize each other, and the result is that there is never any reduction to zero.

Now to come to my criticism. I think Mr. Kennelly has overlooked one point. It occurs very frequently in mathematical physics that the differential equations involved are very simply solved—as in the case here, an exponential or trigonometric function will solve the differential equation. But the difficulty occurs, that in every problem, besides having a function to satisfy the differential equations everywhere, it must satisfy certain boundary or terminal conditions. Mr. Kennelly has considered the case of insulation at one end or connection with the ground. Those are very simple. What you want to know, I suppose, about a line carrying an alternating current is what will happen when there is a motor at the farther end. He has spoken of some lamps, but that he has not treated separately. Now, if you put a motor on there which holds back, there is certainly a difference. Imagine the case of the string. It is obviously a very different matter about pitch, wave-length and all that, whether you have the string fastened rigidly to two pegs at the ends, or whether you have it fastened to a weak spring representing capacity. If it is fastened to a weak spring, and you shake it at the other end, you do not have sharp reflections. On the other hand, if you have it connected to a weight which has inertia, there is another change in the motion—the reflection is different still. In the case of an alternating current motor, there is certainly self-induction. Now these things must produce a reaction there on the line, and cause a change of phase and giving out of power and all that. It seems to me, that it must be treated quite by itself.

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Finally I am always delighted when I see a subject of pure mathematics brought into the field of applied physics, and especially by an engineer. The most brilliant case I recall of that kind was in the case of the French engineer Saint Venant, who solved most beautiful problems in elasticity and got formulæ which are now used by every engineer, I suppose. All engineers before had used an empirical method. The method that I speak of is the same there as here—the method of the application of the principle of the conformal development of one plane upon another. Perhaps some of you wonder how Mr. Kennelly got this Plate I. I did too, but I can guess. In Maxwell there is a chapter on the theory of conjugate functions. The point is to find in two planes points corresponding to each other, so that every line in one will correspond with a line of the other, and

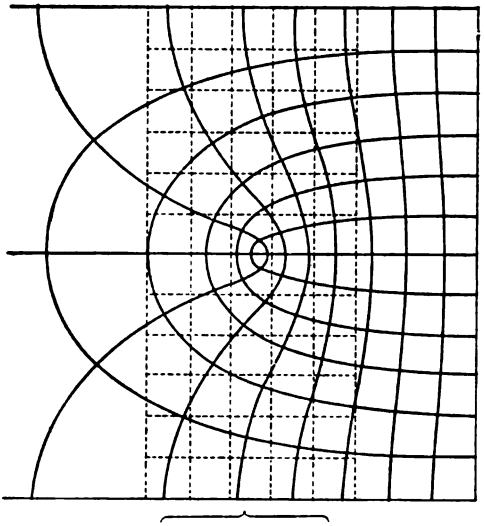

FIG. 12.

$$x'' + i\,y'' = \log(x' + i\,y').$$
$$x' + i\,y' = \cosh(x + i\,y).$$

$\left\{\begin{array}{l} x'', y'' \text{ are rectangular co-ordinates in this diagram.} \\ x' y' \quad \text{"} \quad \text{"} \quad \text{"} \quad \text{"} \text{ Kennelly's diagram.} \end{array}\right\}$

the property is that all angles made by corresponding lines are preserved in the two planes. Here we have the case of the x and y lines in one plane corresponding to the ellipses and hyperbolas in the other plane. This is done by the use of the analytic function, $\cosh(x + i\,y)$ which gives this development. Mr. Kennelly's result has been that you have to measure—having one curve $x = .2$, and the other, $y = .7$ corresponding on this diagram to the ellipse $x = .2$ and the hyperbola, $y = .7$; their point of intersection corresponds to the point of intersection of the straight lines, $x = .2$ $y = .7$. If we go one step farther and transform this plane again so that the circles in this plane go into straight

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lines in a third plane, and the radii which cut these circles at right angles go into straight lines cutting the straight lines just mentioned in the third figure at right angles, we shall have to see what these ellipses and curves transform into. Mr. Kennelly will find the picture in Maxwell, and instead of having to draw an infinite plane he will have to draw only a strip of a finite width, 2π, which will represent the whole thing. See Fig. 12.

The axis of abscissæ here comes into a line in the middle of the figure and goes off to infinity; the middle of the figures go off into infinity and the ellipses go into curves like this, which come around that line. These ellipses pull out here more at the left, and these hyperbolas, which cut these ellipses at right angles, go into lines which cut these lines at right angles. Now you will not have to draw these extra sets of radii and circles which complicate the figure and cover it up with four sets of curves instead of two. All you have to do is to put this figure on coordinate paper, and then when you have measured off, instead of the straight line or ellipse marked $x = .2$, you will have the particular one of these curves marked with that value, and instead of taking a hyperbola you will take this other curve, and the point in question will be the intersection of the two. Instead of measuring this distance from any particular point and measuring an angle you simply measure these two rectangular coordinates. Mr. Kennelly has got the work all done in making this figure, and he has simply to transform this figure into that by taking points which lie on a circle here and marking them off. That will make it easier for the members of the INSTITUTE who are going to use this work of Mr. Kennelly's in their practical engineering to get the results, and they will not have so many lines on the figure. There will be nothing for them to do, and it will be a little further application of the same mathematical principle that he has already applied and might apply here.

MR. CHARLES CUTTRISS:—While I am not going into the mathematical discussion of this question, I would like to say that if I understand the remark of the last speaker correctly, he said that the curves described by the waves travelling through a cable, keep up a uniform period but merely flatten out in a perfectly uniform manner as they travel through the cable.

I would say that I have proved by experiments that this is not so. The cable experimented upon was over 840 knots in length, and the experiments were made for reasons that were very remote from the purpose of this paper.

You will hardly call the period or rate at which I transmitted the current, alternating current; it was about 80 per minute.

The potential began from zero, went up to 40 volts and came down absolutely in the same manner by the same gradation and time in which they went up, and a record was taken at the distant end of the cable on a siphon recorder. The wave, instead of going up in a perfect curve, such as you would imagine

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and coming down on the opposite crest in the same curve, went up in an approximately perfect curve to the apex which was prolonged. The curve then dropped more suddenly to its zero, and in so doing, described almost a concave. This same formation is maintained in larger or smaller curves whether the speed be about 80 periods per minute or 360, the latter speed being the maximum at which I could transmit.

I do not know whether I have described the shape of the curve clearly, so I will try and put it upon the blackboard.

The curve, as you might imagine, rising from zero to 40 volts would be a perfect curve like this — instead of which its shape is more like that.

Fig. 13.

Now, that will prove that it is not the same as the pulling of a string and getting the same movement, only growing flatter and flatter as it travels along.

I have tried for a long time, for purposes which I cannot mention, to obtain this perfect curve, but hitherto have not been successful.

Dr. Webster:—If I may be pardoned for replying to the objection of Mr. Cuttriss, he has quite misunderstood what I said. I by no means stated that the thing would be the same all along the curve. The curve that he has given there is exactly what might be expected. The differential equations are the same as for a wave of water. You have seen the waves running along at sea. They look very much like the sinusoidal wave that we have so much in physics. But when they come in shore on the beach they curl over just like Mr. Cuttriss' picture. There is a figure like that. I cannot say exactly where it is, but I would be willing to wager that there is something on that in Mr. Heaviside's paper. But I am extremely glad he has experimented on it. I have often thought that if I had only some pull on a cable or cable official to make a few experiments I should be only too delighted. I want to ask Mr. Cuttriss a question I never have been able to ask anybody, because I never knew anybody who was in a position to answer it, that is, what is the self-induction of a real submarine cable per mile? If he will tell me that, I shall go home pleased.

Mr. Cuttriss:—That is something that has never been worked out.

Dr. Webster:—I have been engaged in experiments for quite a while on electric waves and such things, and I have got the apparatus for determining exactly that thing, if I only had the cable. I never expect to have the opportunity of doing it.

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If it could be done, and if there was such a thing as a cable which was out of business for a few hours or a few days, we could learn a lot, and I am sure it would be extremely worth while. If there is anybody here that wishes to present a few million dollars or a cable to Clark University or any other, I should be very glad to lend my apparatus to have this done, and I am sure it would be worth while.

Mr. Cuttriss:—I beg to say that the great trouble is that you cannot be at both ends of the cable at the same time.

Dr. Webster:—I do not want to be. I have been planning a long time, in fact at the Congress in Chicago, two years ago, I announced my paper. I had done enough preliminary experimenting to think I had got the facts I wanted. I had the wires that came to the same thing as a cable, and I thought I had the results about these waves, but they were so extremely short, something like two or three millionths of a second, that I afterwards called myself down and withdrew the paper. I have not yet been able to get the wires up, and as Mr. Cuttriss said, get at both ends at the same time. But I can assure him it is not necessary to do that, and I think we can arrange the experiment at one end so that we can get all that we want to know.

Dr. Pupin:—Mr. Cuttriss remarked that in this case we have no resemblance between the pulling of the string and the actual propagation of the wave. Neither should we have, because in the case of a submarine cable, the self-induction is very small, and it is just like jerking at a string whose weight is small in comparison to the viscosity of the medium in which it is moving. Therefore in this case again, the fundamental equation reduces itself to the same kind which describe the conduction of heat. The analogy of the vibrating string ceases, passing into the analogy of conduction of heat. We pass from one physical phenomenon to another, from the vibration of the string to the conduction of heat. So far as the experimental work is concerned, Foucault and some French engineers have experimented on the transmission of signals through air lines, and they found the same difficulty that Mr. Cuttriss found in Atlantic cables, namely that the shape of the wave as it is put into the line at the sending end does not resemble very much the shape of the wave which appears at the receiving end. They found, unfortunately, that although they put in at the sending end a very sharp signal, at the receiving end that signal was not sharp, but it came just like a steep wave front, and then it dragged out into a more or less elongated tail; so that they really could not thereby determine the exact time at which the wave had arrived at the end of the line. But no experimental work has ever been done on these matters in the laboratory. Telegraph lines are always busy, and it is very difficult to perform experiments and be at both ends of the line. But experiments of that kind can be performed. We can make, without very much trouble, artificial

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cables representing long air lines in all the particulars; that is having so and so much resistance per mile, self-induction per mile and capacity per mile, if we simply take the trouble; and I think it would be quite worth while to make some experiments in that direction, especially since the problem is very important and no experiments have ever been made in that line of work.

THE PRESIDENT:—If there is no other discussion, as the hour is late and there is another paper, I will call on Mr. Kennelly to close the discussion.

MR. KENNELLY:—The criticisms which have been raised are speedily dealt with in this case. First of all, in regard to terminal conditions, the head and front of the offending in our paper is alleged to be that, while we deal with an insulated line, and have also dealt with a grounded line, we have not considered the countless conditions that may practically arise where a line is neither insulated nor grounded, but is in some intermediate condition. If, however, you will examine formulas 3 and 4, you will see that they take into account every possible condition, providing of course, that the currents and electromotive forces are sinusoidal. We have, unfortunately, to make that assumption, which is not justified in every practical case, as we know. Look at equation 3, for example; the electromotive force is composed of two terms, the first of which depends on the terminal electromotive force, and the second on the terminal current. If the terminal conditions require that the lag in phase of the received current is a given number of degrees, insert that number of degrees in the current and the results obtained will be applicable to all points on the line. No lag was assumed for the current in Plate III, because there was no object to be gained by the selection of any particular phase difference between the received pressure and current. But of course, it is evident that any apparatus, as for example a transformer or a motor, when supplied with, say a thousand volts at the receiving end of the line, will take a certain number of amperes at a definite lag for any given load, and one is supposed to know experimentally what the lag at any given load will be. If we know this relation for all conditions of load, we simply have to interpolate in equations 3 and 4, in order to determine the pressure and current at any point on the line, provided it can be safely assumed that the current is sinusoidal. Of course, in a transformer or motor, the current is not usually sinuosoidal, and of course, our formulas fail just to that degree. But we know also that we can make certain assumptions in regard to the deviation from the sinusoidal condition of even waves of current that have been distorted by hysteresis. We know that when a current is distorted by hysteresis in a transformer, we can separate the complex wave into two waves, each nearly sinusoidal, and this analysis will very closely represent the actual condition of affairs. I need only refer to Mr. Steinmetz' work

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in this direction, as presented at the Philadelphia meeting last year, to show that that is the case, and therefore we claim that our formulas deal with every possible terminal condition. In the paper we have only illustrated a few terminal conditions, for the sake of simplicity.

We do not claim that we have deduced any absolutely new principles. We know that the fundamental principles dealt with in our paper have been developed long ago; but what we do claim is that we have presented them here for the first time in a simple and practical engineering form.

Now in regard to Plate I, and the question of the way in which it should be most conveniently drawn, we cannot agree with the suggestion of Dr. Webster, for the reason that what we seek is not the rectangular coordinates of a hyperbolic sine or co-sine, but its polar coordinates. In order to draw that diagram, we had to send to Europe for a machine. We could not find anywhere in this country a machine which would draw the lines accurately enough.

In regard to the question that Mr. Cuttriss has mentioned, of course his problem is entirely different from that which we here consider. He is dealing with signals representing the trace of current as they proceed over a long cable. We deal with the effective electromotive force and current, and not with the trace of any single wave. Those waves we show are simply photographs, so to speak, at any moment, of the effective alternating current pressure and current strength at all points along the line, and at all moments that condition will be maintained, although everywhere the current is alternately reversing in direction. We do not of course show what the trace would be of alternating current waves, as recorded for example by the siphon recorder.

Wm. Maver, Jr:—(*Communicated after Adjournment.*) I desire to express my appreciation of the valuable paper which Messrs. Houston and Kennelly have brought before us. It is doubtless true, as several of the participants in the discussion on the paper stated, that to many it will require considerable study before it is thoroughly digested and assimilated in its entirety, but fortunately the paper is on record and, therefore, accessible for study. Furthermore, there are numerous points brought out in plain language and others illustrated by numerical examples, which require only an ordinary understanding to grasp them.

Furthermore in my opinion, the paper is not only valuable but it is also timely, for so much has been said or intimated concerning the direful possibilities of the effects of resonance that some of us had almost began to think, despite years of practical experience with alternating current circuits, having considerable capacity and inductance, that some fine day resonance would astonish and confound us by upsetting things generally. For example, it was only recently that I was informed that resonance

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had been held responsible for the failure of the insulation of an underground alternating current circuit in a neighboring city, which was proven by the fact that, upon changing the route of the circuit, the cable in question no longer broke down.

As my experience of over six years with more than fifty such alternating circuits, representing a total length of about 300 miles of underground cable, had not disclosed any similar case, I was considerably nonplussed. It is therefore reassuring to learn from Messrs. Houston and Kennelly's calculations, that the maximum increase of voltage due to resonance on a circuit such as the one I refer to would be, under the most favorable conditions, about one volt.

The paper further shows that even on the very longest aerial circuits the devices which may be provided to protect the insulation from the effects of lightning discharges may safely be left to deal with the increased voltage due to resonance.

THE PRESIDENT:—We will now have the second paper, by Professor Anthony, on Underwriters' Rules.

[The following paper was then read by the author.]

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A paper presented at the Ninty-sixth Meeting of the American Institute of Electrical Engineers, New York President Houston in the Chair, and Chicago, Manager A. S Hibbard in the Chair, April 17th, 1895.

UNDERWRITERS' RULES.

BY WILLIAM A. ANTHONY.

A recent controversy, in relation to inside wiring for incandescent lighting, has suggested to me the importance of bringing out a full and free expression upon the subject, from those whose experience gives them the best right to speak, and I venture to bring the matter before the INSTITUTE in the hope that it may provoke such an expression as may have some influence in determining the character of any changes in the rules for construction that may be proposed, or in fixing the interpretation to the rules now in force. The present rules are, of course, the result of a process of evolution, and I think every one will admit that the process has been one of progress. In early days of electric lighting, the desire to conceal the wires led to fishing them in between floor and ceiling and between plastered walls, as had been done with electric bell and burglar alarm wires. Fires occurred, and were ascribed to the electric wires, sometimes rightfully, but no doubt sometimes wrongfully.

Insurance companies took up the matter, passed rules and appointed inspectors. Many of the rules were good, some were only an annoyance to the construction companies. Different boards adopted different rules, and often the inspector was a law unto himself.

Wishing to assist in securing uniformity, and feeling that electrical engineers, who have to do with the practical work of electrical installation, are best qualified to frame rules for electrical construction, the National Electric Light Association, in 1890, appointed a committee to take the matter in hand, and upon the report of this committee, in 1891, adopted a series of rules, which,

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with some amendments adopted at later meetings, may be assumed to represent fairly well the consensus of opinions among the electrical fraternity, as to what constitutes a safe electrical installation.

Rules, substantially the same as those, have been adopted by the National Board, and various local boards of fire underwriters, and are the recognized rules in force at the present time.

The object of all rules is first, to secure a safe and permanent installation; second, to provide for the repair or renewal of conductors in case of failure. It may be said that from the standpoint of the insurance companies, the first is the only object, but surely, conductors so installed that they can be easily overhauled and replaced in case leakage is discovered, are safer for the very reason that a fault is likely to be repaired before any serious damage has occurred.

When highly insulated wires, whose insulation resistance was measured in megohms per mile after immersion in water for weeks, came into use for electric lighting plants, it was natural to suppose that they could be put anywhere, and would last indefinitely. They were put in all sorts of inaccessible places; on the beams before floors were laid, in partitions before plastering, on the lath with iron staples, to be covered with mortar. Some such circuits are no doubt in existence to-day, as perfect in insulation as when first put up; but numberless cases of failures of insulation occurred, and experience shows that such a construction is entirely unreliable. Then came the interior conduit, which it was assumed would serve both as a mechanical protection and an insulator, but it was found not to be entirely reliable in either capacity. It was not impervious to moisture, it was subject to damage by nails, saws and chisels. It was found necessary to prescribe that wire of the highest insulation should be used in it, and that it should not be drawn in until all danger from mechanical injury was passed. Then came the brass armored conduit; but that was not nail proof. Now we have the iron armored conduit, and it remains to be seen whether this will fulfil all requirements.

It has come to be pretty well recognized that no mode of electrical construction is absolutely proof against failure at some point, and that form of construction is best which affords the smallest chance for injury or depreciation, and offers the greatest facilities for repair or renewal in case of failure.

There has been a uniform progress in the direction of greater

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safety and better facilities for repair, from the time when wires were put anywhere, to be covered by floors, or mortar, or built into brick walls, to the iron armored conduit which is offered to-day. To be sure, the cost of the installation has advanced, and the iron armored conduit presents difficulties when alternating currents are employed. To me it seems that the advantages gained are worth the cost, and the difficulty with alternating currents disappears, if the two conductors are placed in one conduit. To this I can see no possible objection when the conduit is iron armored.

In view of the fact that we cannot be absolutely certain that failures in insulation will not occur in any given installation, it seems to me that the foundation principle of all rules for the placing of conductors should be accessibility. Further, no conductor should be placed where its position or its relation to other conductors in any part of its length is unknown. This means that raceways must be provided, into which conductors may be drawn and from which they may be removed at pleasure, such raceways to serve as adequate protection from mechanical injury; or the conductors must be placed in mouldings which are themselves accessible, or they must be supported by cleats or insulators in plain sight.

I believe that past experience would warrant the adoption of a rule that would require the use, for concealed work in buildings of fire-proof construction, where conductors must be carried up steel columns, over steel floor beams, in brick partitions, or in plastered walls, of a raceway or conduit, equal in its ability to afford mechanical protection to that known as iron armored conduit, so installed that conductors could be drawn in or out at any time.

And now a word as to the controversy that suggested this paper:

A conductor has been put upon the market, which consists of a standard Habirshaw wire with its covering of rubber and braid, having woven upon it two additional coverings of extra heavy braid. This additional covering, which is tightly woven on, and from which the wire can no more be removed than from its original covering of rubber and braid, the maker, by an extraordinary stretch of language, calls a tube, and claims for it the advantages of the conduit tube prescribed in the insurance rules. It goes without saying that this wire affords no means of re-

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placing a damaged conductor, and, therefore, has not that advantage of the conduit. As to mechanical protection, it certainly is not superior to the unarmored conduit, and it has not the advantage that the conductor can be left out until the danger of injury is passed. As to insulation against moisture, the added coverings do not improve it, the insulation being entirely due to the rubber covering which is inside of all the braids.

And yet I have just learned that the New York Board of Fire Underwriters, on March 20th, passed the following resolution:

Resolved, "That the Superintendent be authorized, until further notice, to approve the use of the Attix tube and wire, when equal in quality and insulation to the samples submitted to this Board and tested, under the same conditions where tubing would be permitted; provided that there is no splicing or tapping of the wire, but that its introduction shall be in all cases by the loop system; that in new buildings, when necessary to carry it between floors and plastering, it shall be through holes bored in the beams, not less than two inches apart, a single conductor in each hole, out of the reach of nails; and in old buildings, where necessary to carry it within the reach of nails, it shall be protected by some device from perforation; and provided further that the wire and tube be carried intact into the cut-out boxes, and that in no case shall the outer covering be removed before introducing the core wire into the cut-out box."

It will be noticed that the wire is called a "tube and wire," when it is no more a tube and wire than the Habirshaw which forms its basis. The tests referred to, show that, after immersion in water or being imbedded in plaster, the insulation resistance was 20 megohms per mile. But the Habirshaw wire, without the Attix covering, would have shown the same. What then is the propriety of confining the operation of this resolution to the Attix wire? Why not permit the use of any good highly insulated wire under the same conditions?

It seems to me that this resolution is one of those reversions to an ancestral type which we find in all evolutionary development, which is off the general line of progress, and which is destined soon to become extinct.

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Discussion.

The President:—Professor Anthony's paper is now open for discussion.

Mr. C. O. Mailloux:—This paper, with its unimposing title and modest dimensions, is I think one of the greatest importance to electrical engineers. I do not wish to disparage the preceding paper, and it ought not to be any disparagement to say that the paper we have just heard is at least of equal merit, great as is the value of the preceding paper; because although the question of electric wiring is one which seems a relatively simple matter in these days of sines and sinusoidal functions, yet it is one which, when we come to the practical and commercial side of our profession, we have at one time or other to deal with; and there are those of us who have extensively to do with it. I think that we should be very watchful of the construction which is placed upon the rules formulated by the different insurance companies. They may be working for the purpose of making the electrical business better, but that is with them only an incidental consideration; they have not the interest in so doing that we should have. Their interest is primarily to see to it that the installation is made safe from fire. We have a further interest. We have some interest in seeing that the installation is perfect, not only electrically but practically, and that it is a credit to the profession which it represents. I am very sorry to call the attention of this body, (or at least some of the members of it who may not be familiar with it), to the fact, though many of you are familiar with it, that in the matter of insurance rules electrical construction has been handled with a spirit of inconsistency and partiality and with a want of that broad liberal treatment that characterizes other lines of fire inspection. This case, of the Attix wire, is perhaps as good an instance as any, and it ought to be one sufficient in importance to call the attention of electrical engineers to the necessity of our acting, either singly or jointly, in such a manner and with sufficient emphasis, as to let our voices be heard and prevent the continuance of such inconsistencies.

As the paper very clearly puts it, it strikes one as almost absurd to characterize or define as a *tube* a piece of wire which has a solid wrapping of some material supposedly fireproof, applied to it. It is no more a tube than would be any other wire on which might be put a covering braid or some other material than the insulation. I do not see why a simple braid or a simple tape really is not as much a tube; yet we have found ourselves tied hand and foot in many cases by such rulings as that, on the part of insurance inspection authorities. I might mention a dozen cases in my own practice which are equally incongruous, equally absurd, and which have caused needless delay, needless expense, trouble and annoyance. I think it is time that the

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INSTITUTE as a body should protest against a continuance of such rules and such measures on the part of insurance companies. I may state with pleasure that I have heard several representatives of distinguished and prominent insurance companies express themselves in no uncertain terms in regard to the manner in which this work has been done by those who were supposed to represent them and do their best for their business. I have stated to some of them that it has an evil influence on their business. I know of cases where the insured has preferred to do his own insuring rather than submit to the arbitrary dictation of the insurance inspectors. Some of the insurance companies themselves have expressed their dissatisfaction; and they feel, in some quarters at least, that there ought to be a change in policy; that insurance rules ought to be compatible with, and favorable to progress in electrical installations, rather than obstructing it.

MR. WILLIAM J. HAMMER:—I am heartily in sympathy with the gentleman who presented this paper and the gentleman who has just spoken. I think that subjects of this character are of the utmost importance to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. At the last annual meeting I had the honor as the Chairman of the National Electric Light Association's Committee on Standard Rules for Electrical Construction and Operation to present their last report to the INSTITUTE with the request that a committee be appointed to examine and endorse it on behalf of the INSTITUTE in order to secure fuller cooperation and a better enforcement of these rules. Two gentlemen appointed on the committee of the INSTITUTE and who are among the most honored members of this body, made the statement to me at the time that they thought it was inadvisable for the INSTITUTE to take up a matter of this kind, because it was purely a commercial one, and the INSTITUTE was a scientific body. In this connection I wish to say that I heard some one make the remark recently that many members in the INSTITUTE thought it was hard to get papers before this body which were within five miles of the earth. I think we have had admirable papers of the character that have been read to-night by our worthy President and Mr. Kennelly, but there are also other papers which reach a very large percentage of the members, are of vital interest to the professional work that a good many of us are engaged in; and I am particularly interested in this class of work, having been identified for a number of years with the work of the committee of the National Electric Light Association which promulgated the rules now practically used all over this country by the insurance people generally, and I might add, without any credit to the organization that brought them out. I think severe criticism can justly be made upon the underwriters for allowing their inspectors or their experts to bring out rules of this character and pass them, and foist them upon electrical engineers and the public at large. I think many of these things have not been

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treated in as conservative a manner as they might have been. Last year a very earnest effort was made to secure the cooperation of all the electrical interests, including the insurance inspectors, etc., with a view to having one single set of rules go out, having them more rigidly enforced, and having them kept up to date—those efforts, although very earnest, were not brought to a conclusion. Since that time the committee has continued its efforts, and before very long, the committee of the National Electric Light Association, who are recognized as the ones who have brought this subject to the front for years past, will extend a formal invitation to the representatives of the telephone interests, the street railway interests, the Fire Chiefs' Association, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and perhaps some other association or two which will be interested in seeing that proper rules which are conservative in their character and which do not benefit any particular class of manufacturers or any particular industries to the exclusion of others, are adopted; and it is hoped that before this year is out some uniform action will be taken by these organizations which will look to just the step that Prof. Anthony and others have recommended, and which is certainly highly advisable. I merely refer to this now, because very earnest efforts have been made during the past year and they are being pushed very actively by a committee of the National Electric Light Association acting in conjunction with some of these other gentlemen, and the matter will be brought before the INSTITUTE as well as these other bodies within a short time and in a manner which I trust will appeal to them and be treated as being of such decided importance to the electrical interests for the INSTITUTE OF ELECTRICAL ENGINEERS as well as other bodies to cooperate with the National Electric Light Association in its important work.

MR. H. WARD LEONARD:—This subject is one that has interested me for a good many years and I am familiar with the difficulties that have always been met with by contractors in dealing with the rules set forth by the underwriters and the requirements that they lay down. Having installed a good many hundred thousand lamps on different styles of wiring in the past ten or twelve years, I feel that the use of anything such as has been described in this paper as the Attix "tube and wire" is certainly a distinct reversion to the conditions that applied to electric light wiring in about 1885 or 1886. I personally installed work at that time which was done with practically identical materials, and which I think were as good as the Attix tube and wire can be to-day, and it seems to me that the conduit is an essential condition for thoroughly first-class work to-day, and that a conduit to be of any service whatever must be a permanent, reliable, strong tube which will be always there, enabling you to pull the wire out and in, in case of any failure of the wire. I personally am very strongly a believer and always

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have been, at least for a great many years, in placing the opposite poles of a circuit, whether it be a two-wire circuit or a three-wire circuit all inside of a single iron pipe, and I have put in some thousands of lamps in this city in which both poles of the circuit are inside the single plain iron pipe, with quite satisfactory results; and I wish to call attention to a point which may not have impressed itself on all the members, and that is, that in case you do have both poles of the circuit inside of the iron pipe and the system of iron pipe be grounded, it is almost inconceivable that any condition of leakage or trouble in the electric circuit should occasion a fire. In other words, it is my belief that the rules of the underwriters which they have so strenuously urged for the last few years, that when conduits are used that only one wire be placed in each conduit, is merely aggravating the possibilities of fires which could be eliminated by using first class insulated wires inside of a single, metallic conduit. The underwriters apparently have been convinced of this point comparatively recently and have waived that requirement where the wires are placed in an armored conduit. As an indication of the difficulty of securing attention on the part of the underwriters to those whose voices ought to be heard in practical matters relating to electric work, I will say that there exists in this city an association of nearly all of the representative concerns of electrical contractors, and feeling that the underwriters had imposed very arduous and unreasonable rules and in fact conditions which made it more expensive, more difficult and more dangerous to do electric wiring work, the contractors in question appointed a committee when they learned that the underwriters were likely to issue a new set of rules in the then immediate future. They appointed this committee to wait upon the underwriters for the purpose of aiding them in drawing the rules and in arriving at rules which would be mutually satisfactory, and I happened to be chairman of that committee and so can speak about it from my own knowledge. A letter was sent to the underwriters by me as chairman of this committee, expressing a desire to participate in their discussions in regard to this matter, or at least to be given an audience to express our views in regard to some of the points which we hoped would not be inserted in the new rules and which we had considered arduous in the old rules, and the letter was acknowledged with the statement that in case they cared to have any conference with us or to hear any expression of opinion from us, they would let us hear from them, which we never did. I am heartily in sympathy with the general tenor and purpose of this paper and believe that this INSTITUTE is by all means a proper body to express its opinion in regard to matters having so practical a bearing on the work of electrical engineers.

MR. FRANKLIN S. HOLMES:—I am in hearty sympathy with the paper, and am also disposed to criticise the position occupied by the Board of Fire Underwriters.

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I understand the Board to be an organization of business men formed to protect its business interests by issuing and enforcing such rules as will reduce fire risk. Its field is commercial, not technical, and when it deals with technical matters it is liable to act foolishly. As an instance in point, compare the three tables, showing the safe carrying capacities of copper wire, which have been published by it within two or three years. We find that the carrying capacity of a given wire varies nearly a hundred per cent in these different tables. See also the unreasonableness of the Board's rulings in the matter of pipe conduits. It prescribes that iron pipe carrying duplex conductors must be lined. And yet if we ground or short-circuit a service, carried in a plain iron pipe and protected by a 25-ampere fuse, by no possibility can we heat the pipe dangerously hot, at any point in its length. The lining of a pipe, for small conductors at least, does not affect the fire risk one way or the other, and, therefore, the Board should make no such sweeping rules on the matter. Similarly, in this question concerning Attix wire, its ruling is partial. Any continuous duct into which wires are, or may be drawn after a building is completed, whether it be paper tube, brass covered conduit, canvas jacket, or iron conduit, are each and all better than plain wire protected however thickly by a pervious insulation. The insulation of the Attix wire is pervious, and in no sense can such protection be considered as the equivalent of a duct, however fragile or strong. I repeat, I think the Board of Fire Underwriters has limited duty to perform and should confine its action to impartial rules in matters involving fire risk only. It should leave devices and methods which pertain to excellence of construction to others whose business it is.

I am very glad to hear that there is a movement on foot which will effect a conference of all parties interested in raising the standard of electric light installations. I hope the result will be first, a more rational set of general rules, and second, a strict definition of the functions of the Board of Fire Underwriters with reference thereto.

Mr. James Hamblet:—It came to my notice a short time ago that certain buildings in the city of Brooklyn were wired for electric lights and inspected by the inspectors of the Board of Fire Underwriters and approved. The lights were used for a time, and then a certain time after that inspection, they were again inspected and condemned, and the owners were compelled to re-wire their buildings or improve them according to the new rules adopted by the same Board of Fire Underwriters. I also know a similar instance in Brooklyn where a contractor made an estimate for the work and the inspectors were watching him, and the inspector told him that by the new rules a certain new kind of tube was to be used and he must put in that kind of tube. That destroyed his profits on that little job.

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MR. W. J. JENKS:—I feel a great deal of interest in this paper which Prof. Anthony has read, not alone because I am thoroughly in sympathy with the views which he expresses, but also because I think the discussion of the general subject of the relations between the electrical engineering profession and the fire insurance underwriters may, if now taken up by the INSTITUTE, become very profitable. I have had some little experience in representing the incandescent electric lighting industry in discussions with the insurance people during the past twelve years. In 1883, representatives of the underwriters came to study the arrangement and operation of the first three-wire underground system in the world, at Brockton, Mass., of which I then had charge. In 1884 the first schedule of insurance rules adapted to the necessities of incandescent electric light construction of central station systems and isolated plants, was issued by the New England Insurance Exchange, as the result of a careful study of actual conditions by Capt. William Brophy, who was then their inspector, and Mr. S. E. Barton, who was then chairman of their electric light committee. In formulating these rules the New England people followed the example which had been set for them in 1881 by Mr. W. H. Anderson and his associates in New York, in their issue of the first rules adapted to series systems of arc lighting, in that they sought information of those who engaged in the practical work of installing electric lamps, and encouraged suggestions from such people as to revisions which the rules might require. This policy of mutual consultation and cooperation was explicitly adopted by Mr. Edward Atkinson in 1882 when he was president of the Boston Manufacturers' Mutual Fire Insurance Company. Cooperative efforts of this sort have been the rule during all the subsequent history of the art, and in proportion to the cordiality of the relations between the insurance companies and the electric lighting and power people, has been the correctness of the form into which insurance opinions have been moulded. There are a great many examples in the rules, of the truth of this statement, and while I fully appreciate the differences which now exist as set forth in Prof. Anthony's paper, I think the instances thus afforded and the remarks which have been made to-night, should be considered as local rather than as general in their application. The cordiality which has, as a rule, existed for many years, was well illustrated when in August, 1890 at Cape May, two or three days in advance of the meeting of the National Electric Light Association, a committee from that Association met representatives from some of the individual electric light companies and a number of executive men representing the underwriters' boards of different parts of the country, and chose a sub-committee to collate all the available information as to requirements of the underwriters throughout the United States and formulate a revised code. I happened to be one of the members of that sub-

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committee, and the results of our work appeared in the arrangement of what is now the National Code, first adopted by the Western Union Fire Underwriters' Association, then by the National Electric Light Association, and finally (with some modifications) pretty generally by the different boards of underwriters throughout the United States. I believe this code did not appeal to the necessities of the New York Board of Fire Underwriters, or perhaps it might be more correct to say that it is the record of the growth of the business, that the New York Board has desired to have rules which were unique, differing essentially from those which other people were satisfied with. There are several evidences of the correctness of such a theory in the rulings which have from time to time vexed the souls of electrical engineers who have been unfortunate enough to find themselves under the surveillance of some of the inspectors in the Metropolitan district. Other members of the INSTITUTE can, and I have no doubt will, give detailed testimony upon these points. But I believe it will be found that looking the country over, the insurance people are disposed to maintain a feeling of hearty accord with all electrical engineers who are worthy of the name, and in addition to this, to boil down their rules so that they will come to be short schedules of methods which are dangerous and therefore are prohibited, rather than manuals of instruction for the guidance of constructors who know a great deal more about the business than the underwriters ever expect to learn. I remember that as early as 1887 Mr. Barton, to whom I have just referred, who was at that time more intelligently informed in these matters than almost any other active insurance man in the country, by reason of his close contact with electrical central station men, said in an official report.

"Were we again to begin at the beginning, with our present "knowledge, we think we would be inclined, in justice to all "concerned, to issue rules setting forth those practices that we "would *not* permit, rather than stating in such complete detail "what should be done."

My own feeling has been for several years that the underwriters would ultimately come to the point of issuing a list of commandments as to what the electrical constructors should avoid, leaving us to elaborate a set of rules such as have been spoken of to-night, to teach young engineers in detail what they should do in order to secure the best practical results, and I think that list of commandments should begin, as do the most of those delivered to Moses in the olden times.—"Thou shalt not."

MR. MAILLOUX:—I do not think that this subject can be disposed of in the time that remains for this discussion, and for one I feel that I would like to have an opportunity to collect my ideas. I am under the weather this evening, with a cold, and can scarcely formulate my ideas as I would like to. There are one or two facts in connection with the matter which I think

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it might be well to bring to the attention of the meeting and which may serve to stimulate discussion. In the first place I would like to call attention to the fact that the insurance companies themselves are not entirely satisfied with the way the matter has been arranged, and at present out of some forty or fifty insurance companies represented in New York City, there are nearly one-half who have formed a little insurance inspection association of their own; they are no longer satisfied with the inspection made by the official underwriters, but have an inspector of their own. I am very sorry that their inspector is not here this evening, as he is a member of the INSTITUTE and could give us some very interesting information. I trust that he may have an opportunity at another meeting to give us his experience which is, I assure you, quite interesting.

Gentlemen, I feel quite strongly in this matter, because I have had a great deal of experience with the insurance inspectors, not only in this but in various districts, and as Mr. Jenks has very well observed, I found a noticeable difference, of which I will give you one instance. The iron conduit tube was adopted by the New England Insurance Exchange in June last. I had occasion to communicate with them with reference to a large installation at Newport which was in their district. I had found that their rules would not allow me to use an iron conduit, although there were certain electrical and other objections to any other forms of conduit which might be allowed under the rules. I stated the case, urging the electrical objections and the mechanical ones as well, and received a reply the next day stating that the objections were well taken, that they had been submitted shortly before by others, and that it had been decided to allow the iron conduit tube to be used with twin conductors for such cases. Some four or five months afterwards, I had occasion, in connection with several installations contemplated in New York City, to go over the same matter. A question came up almost similarly. I went in person to consult with the officials of the inspection department in New York and was informed by them that they had as yet taken no action in regard to the iron conduit tube; expressing at the same time grave doubts as to the propriety of their taking any action whatever. It seemed to them to be something that was of very doubtful, if any, utility, if not absolutely bad. However, in the same breath almost, I learned that the Attix tube, so called, was then allowed. This was several months before any official promulgation of this "Attix rule" was made, as this conference took place some time in October or November. You can scarcely imagine the feeling with which I heard this announcement. I could scarcely believe that we were in a metropolis and in a progressive age when I heard that we were going to be relegated by official direction back to methods which I, for one, should not sanction. I will state, that as a member of the examining board of this

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INSTITUTE, I would not want to acknowledge or accept as a member, a man who was capable of admitting Attix wire as the rule prescribes. I would consider that he was doing something derogatory to the profession. Although we are still far away from the ideal and the perfect, we who have had practical experience with the different ways of interior wiring, consider the iron conduit tube such a great step in advance that we hailed it with a certain degree of delight, but we were literally told that we must not touch that. Now I submit that when we reach such a point, that the progress of our profession is retarded by arbitrary methods such as these, it is time for us to act. I will give you another case which is quite interesting. I have now in hand a case where the insurance inspectors inspected a large dry goods establishment in Brooklyn. I was called in by the proprietors of the establishment after they had made efforts during several months to adjust the matter with the insurance companies—I was called in by them to see what could be done in the matter. It took me three months to bring about a conference between the various insurance inspectors interested in it. There were some twenty odd companies who carried partial risks on the establishment, it being a very large one. I discovered very quickly that some of these inspectors wanted certain things done and other inspectors wanted that very thing not done, and so on, for a long list of requirements; yet they were all working from the same rules. Some of them told me that I must not allow any moulding to be capped. Others said that that was very wrong; —the rules required it to be capped; and so on through a long list of inconsistencies. I began in June. In October I succeeded in bringing about a conference between the different insurance companies at which I appeared as representative of my clients. I took delight in calling the attention of the seven or eight inspectors present to the fact that they were extremely inconsistent and arbitrary. I put it in those words and stated my reasons clearly, and this particular case furnished me ample reasons. I think it had a salutary effect; a certain agreement was drawn which stated what these inspectors would all agree to agree or disagree about. I had made so many efforts to satisfy them all that I had given up hope of doing so, and I thought all other efforts useless until I had their signatures as evidence to what they would or would not allow. It was no longer a question of rules. It was a question of what their individual preferences or whims might dictate. Now, gentlemen, I think that the electrical profession needs some attention, when it is placed in such a position as that. I think that not only looking at it from a scientific standpoint, but also from the standpoint of dollars and cents, it will pay us to go to the bottom of this thing. I believe that with the proper amount of suasion we ought to be able to place ourselves in a position where instead of being dictated to we may ourselves dictate to some extent what is proper. I do

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not think there is a more competent body in the United States to formulate rules and restrictions, to prescribe what is a proper thing to do in connection with electric wiring, or what is proper and desirable from the engineering standpoint. I submit that men who are business men merely, though they may have experience, are not so well fitted as those who have had the training and the experience of years, to do this. I think that with all the scientific men and all the practical men that this INSTITUTE contains, it is more competent than any other body to dispose of this question. I am in a position to assure this body that it has sympathy from the outside, that it has sympathy from the very ranks of the insurance companies, which is saying a great deal; because I have already called to your attention the fact that they have dissenters, men who are dissatisfied with the way their business is transacted, and they are only waiting for a word of sympathy or encouragement, or some little energy on our part and on the part of all the other associations interested in the electrical industries in order to give us a helping hand and bring about the desired change.

MR. JAMES I. AYER:—It is very gratifying to me, having worked with the Electric Light Association in relation to these rules for some years, to see the interest taken by the INSTITUTE in this matter. I think that if any additional arguments were needed I can cite a case which perhaps touches the engineer a little more directly and forcibly than some of the points made to-night; that is the tendency of the inspection department of the Board of Fire Underwriters to usurp the prerogatives of the electrical engineer; in other words to issue certificates to contractors which pass as current coin, as evidence that they have got what they paid for—a first-class electrical installation. There is not an engineer here engaged in practical work who has not run against it, who has not seen passed what should not have been passed, and the investors, the men who are paying for the installations, would have been very glad to pay the engineer's fees if they did not feel that they were getting something for nothing from the Board of Underwriters. A case of that kind came up only a few months ago where a very large installation was being made. The specifications were made partly by the manufacturing company and by the architect who had a little assistance in getting them out. But after the contract was awarded, while there were unusual electrical problems involved in the construction work, the parties paying for the installation declined the services of an engineer because they thought they did not need one. They had a competent contractor and realized that it was all right. Later on, when the installation was about to be completed, some comments were made by engineers who observed the work and said it was bad and all that. The question was raised in the Board of Directors—it was a very large corporation—as to whether it was all right or not. Some thought it

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was; they advocated the acceptance of the contract as tendered by the contractor, but the point was raised that there was a lack of thorough workmanship. Immediately, the contractor brought in the argument that the insurance certificate that he possessed was an evidence of what they had got; that they had everything that they could demand or desire under the contract. The work was accepted. A month later they paid a considerable fee to an engineer to tell them what the matter was—why they could not successfully operate the plant. It took about $20,000 to correct the evil, and they paid an engineer to tell them of how little value an insurance inspector's certificate is. It is not often they come out that way—that the engineer profits in the end by it. But it is a fact that the fire underwriters are stepping into the shoes of the electrical engineer; they are interfering with his profession, his businesss, and I know, as Mr. Hammer has well said here, some of the members are anxious to have papers read here that would "get within five miles of the earth occasionally." We all know that this question of insurance rules was regarded by many as something beneath the dignity of the INSTITUTE. It has been so expressed; it has been so treated. But I think that as the thing has taken shape, it is clear to all the members that it is essential that this INSTITUTE take some definite action.

MR. W. J. JENKS:—I want to suggest that we have with us to-night a gentleman who, though not a member of the INSTITUTE, is well-known to almost all of us, at least by his reputation, as one of the most experienced insurance men in the United States, in those relations with the electrical people which we are now discussing. I refer to Mr. C. J. H. Woodbury of Boston, for many years Vice-President of the Boston Manufacturers' Mutual Fire Insurance Company, and now connected with the American Bell Telephone Company. Mr. Woodbury now stands in a position where he can without prejudice give us accurate information in regard to the actual feeling of the underwriters toward the electrical business, and the steps that are now being taken toward the end which has been considered in this discussion so desirable of attainment.

THE PRESIDENT:—We should be pleased to hear from Mr. Woodbury. I trust Mr. Woodbury and the members of the INSTITUTE will excuse the President who has to go to Philadelphia to-night and must leave now in order to catch his train. I will ask Vice-President Hamblet to take the chair.

The President then withdrew and Mr. Hamblet took the chair.

MR. C. J. H. WOODBURY:—I came here this evening as a guest and to listen, not expecting to take any part in debate. My former position for a number of years was in technical relation to underwriters of manufacturing property, and I had occasion to have an intimate knowledge of the policy of the insurance companies in regard to electric light and power installation, and as that is now with me something of the past, I can perhaps look

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at the subject from a disinterested standpoint. There were a great many electric lighting rules, so called, made by local bodies of underwriters, at times conflicting bodies. In 1893, shortly after the last issuance of the rules of the National Electric Light Association, there was formed in Chicago what was known as the Underwriters International Electric Association, the name of which has since been modified by the change of International to National. Suffice it to say that they adopted a set of rules which were in most respects along the lines of those of the National Electric Light Association. There were, however, some points of difference, and these rules have had several amendments which have been prepared and promulgated from time to time. Two months ago I had occasion to make definite inquiries throughout this country in regard to these electric lighting rules. I found that while the rules of the Underwriters National Electric Association are at the present time very generally adopted, yet there is a great difference in their promulgation and enforcement, and that is a difficulty which seemed to be an inevitable one in the early stages of the work, but will grow less and less pronounced as time goes on, because the insurance companies will have a better trained set of men. At the meeting of the National Electric Light Association I had some unofficial assurances which I was able to present to the committee, and they made a report which has been received with a great deal of favor in insurance circles. At the present time the affairs of the National Electric Underwriter's Association on the subject of these rules are in exceedingly good and competent hands. The chairman of the Electrical Committee is a member of this INSTITUTE, an electrician of accomplishments and standing, and one who in addition to his technical education has had a very extended practical experience in electric lighting and in telephony and telegraphy. All of these parties perceived the necessity of certain amendments and also the necessity of a unification of the whole set of rules, because this question of the function of these rules is not one which can be sub-divided and separated one part from another by any line of demarcation. It begins with the design and extends to the construction, the installation and the maintenance of all electrical apparatus of whatsoever kind or nature, whether it produces quantities of energy which can be converted into heat sufficient to cause a fire, or whether it pertains to the inherently harmless instruments, from battery circuits, but which may be, and are in certain conditions, a possible source of danger by reason of their exposure to the heavier currents used in lighting and in power. These questions are fully recognized and can be treated in only one way, and that is by a conference representing all of the various tributary interests. I am sure that the underwriters are alive to it and that they aim towards that end, because I judge from their representations to me to the extent to which I represent one of these interests of

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electricity in this matter. I am looking forward to a conference which will occur in the immediate future representing, I do not care under what head, all of these various electrical interests and which will result in the unification of the electric lighting rules, and it is through that means and through that means alone, that such a result can be obtained. It should be conceded that it will take time for the training and development and selection of persons competent to enforce these rules adequately and justly.

THE CHAIRMAN:—The importance of this subject seems to demand that it be referred to a committee. We have a letter here received from one of our members who is ill. The Secretary will please read it.

THE SECRETARY:—This letter is from Mr. Fremont Wilson, a gentleman who I think has been referred to this evening. I will read an extract referring to the subject:

"If Prof. Anthony's paper is discussed, I hope it will be deemed of enough importance to have a committee of five appointed and a resolution passed, and a letter sent to the New York Board of Fire Underwriters, requesting the privilege of the audience of our committee to appear before the New York Board in relation to the non-observance of standard rules, etc., and to prove to the representatives of the New York Board the injury they are doing to the electric light and power interests throughout the country, by the peculiar methods that have been in vogue for the last two or three years.

THE CHAIRMAN:—What action will the INSTITUTE take upon this letter of Mr. Wilson?

MR. HOLMES:—If this committee, which it is recommended be appointed, is to simply consider what is advisable and appear before the Board of Fire Underwriters, I am in favor of its appointment. But I am not altogether clear, as the resolution is phrased, that the committee will not be formed with instructions. I am in favor of such a committee.

THE CHAIRMAN:—It is proposed to refer the whole subject to this committee for action and report to the INSTITUTE.

MR. HAMMER:—I would like to suggest as it has been stated here to-night, that the matter is already in the hands of the National Electric Light Association and that their committee will extend an invitation to the INSTITUTE OF ELECTRICAL ENGINEERS, as well as representatives of the other interests, and that the matter will then be taken up, not dealing with specific cases but with the whole thing in a broad gauge way. While we may move a little bit more slowly in that way, I think perhaps by joint action going about it thoroughly, we will accomplish more than by having the INSTITUTE refer the matter to a committee in the way proposed.

MR. MAILLOUX:—I agree with Mr. Hammer that the matter ought to receive more deliberation before we act. At the same time, I feel that there ought to be a committee representing the

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on the subject. I also feel that further discussion ought to be had on the subject, I think that there are others, who would be present at another meeting perhaps, who would be able to contribute to the discussion. This subject is too important and it is of too much interest not only for the welfare of the society but for the individual welfare of its members, to be passed over lightly. So far as the appointment of a committee is concerned I would be willing to leave that to the Council. I think the Council is competent to appoint such a committee and to give it proper constitution, but I think the whole matter might be well laid over to the next meeting. I would make a motion to that effect. (Seconded).

THE CHAIRMAN:—If it be your minds that this discussion and the appointment of the committee be laid over till the next meeting of the INSTITUTE, please manifest it by saying aye—contrary no.

(The motion was carried and the meeting adjourned.)

DISCUSSION IN CHICAGO.

A meeting of the Western members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was held in the Electricity Lecture Room of Armour Institute, on Wednesday, April 17, 1895. The meeting was called to order by the Local Secretary, Mr. B. J. Arnold, with about sixty members and visitors present. Mr. A. S. Hibbard was elected Chairman for the evening.

The paper, on "Underwriters' Rules," by Professor William A. Anthony, was read in detail by Mr. Arnold.

MR. CLARK C. HASKINS:—The subject matter of the paper of Professor Anthony is one of very proper interest to all who are desirous of advancing the art of electrical construction. I trust that every member of this association feels similarly in that regard, and is ready to further the good cause in every reasonable manner.

I note what the Professor says about the object of all rules, as he states it:—

"1st—To secure a safe and permanent installation.

"2nd—To provide for the repair or renewal of conductors in case of failure."

I agree perfectly with the gentleman. The three R's of electrical line maintenance are removal, repair and renewal, and the more readily these functions can be performed, the better for the plant, the constructor and the owner. Time is the only test of electrical appliances, and especially is this true of insulation. The conduit system is comparatively new. The electrical fraternity has carried it through several stages or moltings, as has been suggested in the paper under discussion. In its first embryotic condition, it was assumed to be a perfect insulator, and capable of

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thoroughly protecting a couple of dry cotton-covered conductors —ordinary magnet wires. It didn't do it. There were several serious faults found in it, both electrical and mechanical. A second molting, and it still failed to fill the requirements, and again there was a change. We are now experimenting with the latest, and let us hope, the perfect conduit.

The public is complaining at the advanced cost of proper installation. It is extremely difficult to make an ordinary consumer understand the hazard of a poorly constructed plant. "He knows," he says, "plenty of plants that have been running right along for years, not built any better than" the cheap one he is running, or the cheap one he wants to build, "and they have never felt the need of better construction." I have occasionally seen such an individual converted in an hour by an object lesson, when months of argument would have been lost on him. The teaching of the public in any new branch of practical education is difficult and slow. The reason for this is that it costs money if one listens to reason and adopts the best systems and methods—and when one individual is convinced, his lasting wants are at once supplied; but his next door neighbor has to be labored with equally patiently, and long. In this system of education the class consists of single individuals—there is but one scholar in the school, and he is as often at the foot as at the head of his class. Now, between experimenting for inventors and making converts of purchasers, the constructors and engineers will have their hands and heads busily employed for some years to come.

My idea of a conduit is simply a something in which electrical conductors can be run for:

1st—Mechanical protection against injury.

2nd—Ease of removal and replacement for any cause or purpose.

But, in considering the insulation of a wire to be placed in a conduit, the insulation of the latter must not be considered, while at the same time if the latter is lined with a good insulating material, the conduit is that much better, and the installation that much improved.

I think the case before us a plain one. If a solid covering tightly woven outside a conductor will permit of the removal of that conductor, and its replacement by another, then the covering becomes a conduit. Whether a wire which already shows 20 megohms insulation resistance is any the less a good wire for being mechanically covered by extra braiding is scarcely a debatable question; but it does look unreasonable for any Board of Underwriters to accept one such wire for any purpose, and deny the same endorsement for similarly constructed conductors which will bear up under the same tests.

I think the day will come sooner or later when this whole matter will be solved by either conduits everywhere through

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buildings, or raceways constructed in the walls and ceilings, or even better, open work everywhere. I look upon the last as the acme of good construction, if it can be reasonably accomplished.

THE CHAIRMAN:—It will be of great interest to hear discussions on the various points which the paper brings out, and we should like to hear from as many on the subject as possible. We are fortunate in having with us to-night a representative of our own Underwriters' Board, whose work is directly in this line, and I would ask Mr. Merrill to enlighten us on this paper from his point of view.

MR. W. H. MERRILL, JR.:—I thank you, Mr. Chairman, for extending to me the privilege of speaking at this meeting.

I regret that the paper by Prof. Anthony does not bring out the useful criticisms and suggestions which I had hoped from its title that it might contain. I had expected to speak on behalf of the underwriters in answer to criticisms which might be made of the National Code of Rules, which we have worked on from year to year for such a length of time, and which is now almost uniformly adopted by underwriters' organizations and municipal departments throughout the country. Instead, I find the paper starts with a brief sketch of the history of rule-making which I cannot agree is correct in the share of this work it attributes to the insurance interests, and devotes the remainder of its discussion to a certain resolution adopted by the electrical committee of one local board of fire underwriters. Discussion of either of these points will be of little benefit to either the electrical or the insurance interests of the country as a whole. Much good would result from an intelligent discussion of the National Code as promulgated by the National Board. If there is any organization outside of their own employees that the insurance interests should look to for technical information which would lead to the promulgation of more specific, comprehensive and equitable rules, that organization is certainly the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

I do not think I am exceeding my authority, in stating on behalf of the electrical committee of the Underwriters' National Electric Association, that that body would welcome any suggestions or criticisms, members of your INSTITUTE can give us either collectively or individually.

Fair and disinterested intelligent discussion of the many technical points to be considered in framing any set of rules is the only way to arrive at the best results. You have men among you, splendidly trained specialists, who are undoubtedly more competent to deal with many of the problems presented than are our inspectors. No one man can master the wide field covered by the science. Yet the insurance inspector is sometimes criticised for not having performed this feat.

Underwriters, as a body, are too closely cognizant of the part electricity is playing in their loss reports, not to welcome any aid

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that can be given them by the men who are responsible for the service electricity has rendered, and perhaps for some of the pranks it has played. Whenever any man among you judges it would be for his or your interests to help us in our endeavor to properly regulate practice within safe channels, I promise you that the national body will not refuse to cooperate with him as far as lies in its power through the promulgation of sensible amendments and extensions to, as well as interpretations of the National Code of Rules.

THE CHAIRMAN:—I am sure we are very much obliged to Mr. Merrill for his very interesting talk, coming from a point on which we are not generally posted. There is another view of which we have heard nothing as yet, which is very important, and that is the view of the wireman. It would be well for us in bringing all the light possible to bear on this paper, if we could hear something from one who is in the wiring business. We have with us this evening Mr. Arthur Frantzen, who is actively engaged in the wiring business, and I know that he can give us something that will be interesting as well as instructive to us.

MR. ARTHUR FRANTZEN:—My discussion on the Underwriters' Rules will bear more on a contractor's view of the rules rather than a technical one. Mr. Merrill, I believe, has cited very clearly what good construction embodies; yet there are many things contractors must contend with, that underwriters seem to overlook: one being that all the most of our customers care for is the result at the cheapest figure possible, and the unscrupulous contractor gets the job every time, installing his work according to his interpretation of the rules, which differ according to the standard of education of the reader. Should his conscience be too elastic, the next thing is to conceal the defective work, or subsidize the inspector (were such a thing possible), in order to have the work passed. It is not the rules that prevent poor construction, but rather the practical supervision and enforcement of the rules by the inspectors. A case in view, that I know of, will show what I mean by practical, and showing the necessity of having inspectors experienced wiremen.

A contractor installed open wiring for a motor on knobs, and as the proprietor was in a hurry for power, the contractor connected his meter loops together temporarily and left joints unsoldered or taped until the meter was installed. In the mean time, during the contractor's absence, the inspector calls and examines the work, when, Lo, behold! he finds a most flagrant violation of the rules, and proceeds to cut off the two joints for exhibit "A" and "B," and the poor contractor became 10 inches short on his meter loops. Now, had the inspector been a practical or experienced wireman, he could readily have understood the case without any explanation.

In conduit work we have various experiences, and find that the only case when it is used as a complete system of raceways is

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in large office buildings or fine residences. The general public as a rule will not pay for so expensive an installation if they can possibly avoid it. As regards the various conduits in the market, I find that where the lights are all in a small district; circular loom or canvasite makes the best work on account of its flexibility, but for office building work, with long runs, brass armored conduit is preferable; but the conduit to install is the single tube system of iron armored conduit. It is the only conduit you can install, and go on a vacation and return to find everything perfectly intact. The only drawback is its cost, and yet the single tube iron armored system is practically as cheap as the double conduit system of brass armored.

Nevertheless, conduit at its best has many drawbacks, such as breakage, inflexibility and liability to injury, which requires constant watching. The class of construction that gives the best satisfaction at all times, if done well, is open knob or cleat wiring. Here you have something neat to inspect, if well done. It is always accessible, and therefore changes are easily made. Of course, this would never apply to residences or office buildings; but in such cases a combination of special ornamental picture moulding and direct and short runs of conduit from same to outlets makes without a doubt the cheapest and most satisfactory wiring installation.

Trusting I have not wearied you with a rather irrelevant discussion of rules which prove too much for us, if interpreted differently from our worthy inspectors, I will close with the hope that our cause may be appreciated more fully by underwriters and the public in the near future.

Mr. L. Gutmann:—I am not a wireman. However, in regard to installation work, would say, that I divide up partly with Prof. Anthony and partly with Mr. Haskins. I do not think that it is a good practice to have a wire tightly located in tubes. On the contrary there should be plenty of air space between the conductor and the tubes, which by preference should be iron gas pipes. The conductors should lie centrally and be held away from the armor tubes by non-combustible insulators.

We cannot make iron rules and predict a given style of installation work to be the best. While conduit wiring in many cases is the more substantial, the open wiring will have its advocates in many places; the main reason being that with the same security of insulation we have cheapness and accessibility.

For a general plan of wiring I would use one or two inch pipes for all conductors to be placed in a vertical position and going from floor to floor, while all horizontally placed conductors, including fuse blocks, etc., may be placed in brick channels with removable fronts, which channels may be easily concealed if placed in the cove of the cornices, or else form part of the cornice of a room or hall. I do not think it worth while to dwell on the point, that a braid should be an insulated tube, as we all

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know that this is a fallacy on the surface of it; besides a braid cannot be a substitute for an armor, nor does it provide for the air space considered desirable between shell and conductor.

THE CHAIRMAN:—The paper itself is, of course, an immediate reference to what has been called an Attix wire or tube. If there is anyone here who has had experience with Attix wire and who can speak in its behalf, we should be pleased to hear from him.

A late ruling has passed on this form of wire against others, which might be readily made. It is interesting at this time, when we have presented to us this paper on underwriters' rules, to bring out the fact that the representatives of the Underwriters' Board and the various lines of business are coming closer together in their views. I realize it very much in my business, and I have no doubt that you gentlemen, who are putting in electric light wires, also find it so. We are finding that the representatives of the underwriters are going at the questions involved in better fashion, and I am sure that we shall soon find a better ground plan on which to meet underwriters.

In our telephone installations we are using greater care than ever before, and the work is in many ways getting to be more satisfactory. The use of trolley and power wires has brought up a condition of things in which overhead wires are often made to carry extraordinary currents. This has only been touched upon in this paper, but I think that, in closing our meeting, we may add what may be but an expression of opinion, though I think you will all endorse it, that the subject of underwriters' rules and the subject of what we may do with our wires influenced by currents which they are not supposed to carry, is one of much importance and is worthy of a great deal of thought and a great deal of work. It is to be hoped that the work, as it goes on, may be brought out, not only at these meetings, but especially at meetings of our representatives with the underwriters' representatives, so that we may not be working in the dark and doing our work over, or doubling it.

MR. B. J. ARNOLD:—In 1889, while in charge of the St. Louis office of the Thomson-Houston company, I was called upon to reconstruct the lighting plant of the Southern Hotel, which consisted of a 50-light T.-H. dynamo with fifty 2,000 C. P. lamps running in different parts of the building. The plant was originally installed by the T.-H. company, with underwriters' wire. This wire was run under the floors and fished through from one hole to another. The result was that it came in contact with the iron beams of the building in many places. These iron beams consisted of old railroad rails, out of which the hotel is built, as the proprietor was largely interested in a railroad which had recently relaid its tracks with heavier rails, and the old rails were utilized in the construction of his building. The wires were supposed not to touch the iron, but as the lights for some inexplainable reason would suddenly go out at times, and

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start up again as suddenly as they went out, without the defect appearing to be in the dynamo, the conclusion seemed to be that as the building was infested with rats, they occasionally stepped on the wires and brought them in contact with the iron of the building, causing a momentary short-circuit. It was not only severe upon the rat, but upon the lighting service, and caused great dissatisfaction. The management of the building had become thoroughly disgusted and threatened to throw the plant out, as they had fooled with it for about three years. They sent our company word, that unless the thing was fixed, they would abandon the plant. After looking it over, I decided that the best was none too good in this case, and as I feared that with even the best insulation available, the rats might chew it off and bring the wire in contact with the iron beams again, I adopted the only conduit system that occurred to me, as follows:

We secured bamboo fish poles, cut them in lengths of about six feet each, bored out the pith and threaded them upon okonite wire, and wired the building throughout in this manner, started up the plant, and so far as I know there has never been the least difficulty with it from that time to this. The management were to have 60 days to test the plant in before paying for it, but they sent me a check in thirty days with a letter, saying they were satisfied.

I believe this is the first case of interior conduit on record, but as I was more interested in getting the plant to work satisfactorily than in any personal compensation, I did not think of patenting it or attempting to protect it. and relate the instance here as it seems applicable.

THE CHAIRMAN:—The paper and discussions have been of more than usual interest to us, as they seem to be so much in line with our daily work. I am sure that we are all very much obliged to the gentlemen who have kindly spoken to us this evening, and have given us their ideas on this subject. If there are no further remarks, a motion for adjournment is in order.

[Adjourned.]

DISCUSSION CONTINUED, NEW YORK, MAY 21, 1895.

THE PRESIDENT:—It was decided at our last meeting that Prof. Anthony's interesting paper on "Underwriters' Rules," which for lack of time could not receive the full discussion that its merits and importance demanded, should come up for discussion this evening. I will therefore ask that the discussion be opened by Prof. William L. Puffer of the Massachusetts Institute of Technology, and the subject will then be open for discussion by any member who wishes to take part.

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Discussion.

Prof. Wm. L. Puffer:—I must confess that I was somewhat surprised when I read the notice announcing to the members that I was to open the discussion on this paper, especially as it was a paper that I did not hear in the first place, and the discussion of which, taking place either here or at Chicago, I have not very carefully read. I looked over the proofs this morning but somewhat hastily. I have been very much interested in this general matter of insurance rules for quite a number of years, and especially the last year or so. I think I may say that I fully agree with Prof. Anthony in nearly all the remarks that he made about the subject of his paper, which branched off, I think, towards the close, on to a particular form of insulation of wire, which was termed, I believe, a tube. I agree with him most decidedly that the mere fact of putting a braid, no matter how good it may be, over a wire good or bad, does not in any sense constitute a tube from which the wire may be removed. I take the ground that the presence of a mechanical covering on the outside of a wire is a very desirable thing as increasing the life of the insulation, and in that way to be encouraged; but not in the sense of a tube, and it should not be used as in ordinary work. In my own mind I have had the notion for quite a while that any electric wire ought to be mechanically protected if that wire was in a position where there was the most remote possibility that there could be any interference with it; and I remember the first occasion when I had to consider the matter seriously was in the laying out of a lighting system in the iron stack of a large library, in which case it seemed desirable, after looking the ground over, to recommend—and this, if I remember correctly was just before the days of the first tube—to recommend that in that library, rubber covered wires should be used, and that two wires should be put together and pulled into common iron gas pipe which should be cut with due care in removing the fins which are left by the cutter. I believe to-day that really is the best position for wires subject to mechanical injury, for you cannot easily hurt anything inside of an iron pipe unless you have an enormous amount of power at command which is not likely in the average place. Of course when we come to consider the iron pipe we must draw a distinction, I think, between the use of alternating currents and direct currents, for I know that if we have alternating current work, and if we attempt to put a single conductor in an iron pipe there will be difficulty. It will cost too much copper on account of the false drop we get due to the presence of iron. Also there is the liability of trouble due to the mere hysteresis loss of iron undergoing the various cycles of magnetization. So that it would seem desirable, to me at least, to twist the wires rather than to lay them parallel in the same pipe. As even a twisted pair of wires in an iron pipe will have a false drop, it is much better, in my mind, to put those wires

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in the form of concentric cables. But I do not believe in the usual statement that those two wires should be insulated by something that practically is no insulation at all, that is, a layer of ordinary cotton threads. For I believe if insulation is worth having at all, we ought to insulate between the wires, aiming to keep the wires apart rather than afford an opportunity for the wires to come together and break down the system. With the wires in pairs in an iron tube, if the fuses are properly proportioned, there will be no trouble from burning holes in the pipe itself, except in the case of very large conductors. Under those conditions there is, of course, the possibility of melting tube, wire and everything else.

In the discussion of this paper there was what I might call a general uprising, in which the insurance rules and insurance people and things of that sort were treated rather harshly. But you must consider that the insurance people have a very wide field. They have to meet many considerations on every side, the consideration of the various contractors, the cheap Johns, and the man who is paying the bill, and taking it all together it is not an easy row to hoe. I do not agree with them in all points. I think there have been mistakes in the insurance rules and that there are mistakes in them to-day—such, for instance, as to what a safety fuse is. The statement, as it rests now, I think is something like this: "The safety fuse shall be stamped with the number of amperes it will carry indefinitely without heating," or something to that effect. Well, we know that a good sized piece of copper might be stamped 2 amperes, and we could safely guarantee it against heating with that current. That is one of the little loop-holes which are in the rules. Of course it should read "That it should just melt, etc." The Associated Factory Mutual Insurance Companies of New England have seen fit in their Inspection Department to take up the general question of inspecting electric risks, because they have had trouble; there have been fires started under conditions where they should not; it is true they have not cost very much money up to the present time, but they may cost a great deal. Upon looking over the style of risks of these companies and seeing that they really were selected risks, or mills generally—no stores, no show-windows, no houses, no fire-traps, but mills in which the æsthetic side of wiring plays no part at all, it seemed best to me and to the department at that time to modify the rules, which we took in the main from the pamphlet issued by the Underwriters' National Electric Association, and giving due credit in our books for what we took, then modifying, changing and leaving out a great many rules which in our judgment did not apply to the mutual risks. It seems to me that the National rules as they stand are not really what we might call up to date. They take no account of some of the newer forms of transmission, the newer dangers and the newer precautions which should be taken. While in

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general I believe in sticking to one set of rules throughout the whole country, it seemed best to make certain variations. I may say that the Inspection Department is a department maintained by, I believe, twenty insurance companies—mutuals—for mutual aid in preparation of drawings for their plans, sprinkler layouts and general engineering questions, and also to lay out and maintain a very carefully planned set of inspection routes, keeping men travelling around the different mills all the time, each mill being visited, I believe, about four times a year. The work of the department is in general advisory, and it aims to meet the mill men in a friendly manner, to meet the contractors in a friendly manner, and to do all possible good without stirring up any bad feelings. The scheme of rules as we got them out is arranged in some such way as this: In our introduction we admit the uniformity of standards as a desirable thing, and then we have to depart from it on account of inability to agree, which is the general reason for want of uniformity. The general plan of our rules is something like this: We have divided them into classes, the first class being generators as a whole; the second class being electric motors as a whole, and then comes arc lighting as a whole; then low potential systems; then high potential systems for power transmission in general, and there is where the danger lies now, I think, mainly. Then there is the electric railway class, the storage battery, the welding, and the foreign or private wires as we call them. We have taken great care to give due credit in our book to all the rules which we have taken bodily from the Underwriters' rules as issued previous to the 1st of January. Any changes which we have made, even to changes of grammatical expression, and any new rules, have been marked very carefully with a large block letter to distinguish them from the rules which they may have replaced. We then say in large print on the page opposite the first page of rules, that these rules are to be considered as carefully drawn specifications indicating what we believe at the present time to be the best form of construction for mill work, and advising that all contracts for new work have a copy of the rules bound in as a part of the contract, and then we go on and give our rules. Under each rule we have written very carefully a description or explanation of what is meant by that rule, for in our work we find that we can very often convince a man and lead him to our belief by telling him the reason why, when we cannot do it by telling him that he must. Under the head of grounding lightning arresters, for instance, we describe how to do it and why certain things are bad. And so under everything. We explain as well as we possibly can and get out what seems to be to us a good set of rules. The only objection which we have met with up to the present time—I expect to hear a number before the evening is over, however—has been due to only one rule which we have modified, and that rule which we have modified is the rule about sockets and lamps.

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Now the regulation rule says, that the shell of the lamp socket shall be insulated from the circuit. In addition to that we say "nor should any exposed part of the lamp base be a part of the circuit," for you know well enough that every portable lamp and every drop-lamp cord is handled by everybody—Tom, Dick and Harry, in the basement, in the attic, in the cotton room where there is loose stuff, down in the well or where it is wet, and there is no reason, in my mind, why the exposed part of the lamp base should not be insulated from the circuit; for there is no use in carefully insulating the holder and the socket and the guard ring for holding the shades, and then put in a 50 C. P. lamp or even a 16 C. P. with a great shell outside and leaving that in connection with the circuit with all the dangers that abound when there are portable exposed parts of the circuit, or exposed parts of the circuit in such places as to be within reach of everybody.

There is another matter too, in which we have departed, and it is the subject that I wanted to bring up, especially as my share of the discussion of this general paper on insurance rules, and that is the question of the carrying capacity of wires. Under that head there is a great deal that can be said. You remember that in the old insurance rules previous to the 10th of January, when the changes were made, the carrying capacity table was based on the experiments of Mr. Kennelly some years ago, which experiments, we must all admit, were very carefully carried out, having a scientific basis and depending on practical measurements.—just what we want when we fall back on any particular thing as a standard—something that we can back up and defend. Now about the last part of December, I believe, and in the official papers which came out about the 10th of January, the Underwriters National Electric Association issued a set of ratings—two of them, in fact, one for concealed and one for open work. The concealed work table has been increased 25 per cent. over the old table, which was based on Mr. Kennelly's figures, and the open work, meaning cleated work overhead, has been increased 75 per cent. Now, at that time, we could not see our way clear to adopting all those changes, for it was quite plain to my mind at that time, that we were running altogether too close to the point where the insulation of the wire would be very seriously injured, and perhaps in this connection I ought to say what the table used by us at that time was based upon. It was based on a recommendation make by a large and thoroughly scientific committee of the English Institution of Electrical Engineers, who reported that in their opinion no wire should ever be heated to a point higher than 150° F. In their experience they had learned that rubber and rubber compounds on an average began to disintegrate at 150° F. We have taken some trouble to find out whether or not the average American wire would come under this same classification, and we find that the average statement is about the same. That means that the average rubber wire can

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be trusted only up to 150° F., or a rise of 75° over the average temperature of the atmosphere. Then, taking that point as the ultimate limit, the English engineers recommended that the wire should not carry over one-half that current which will heat the wire up to 150° F., thus providing for a safety factor of two; this one-half current will produce a rise of about 19° F., which of course is very low. Now, with respect to these new ratings the increase of 25 per cent. and the increase of 75 per cent., there is in the official announcement which I have here, no authority for the increase, no excuse, no reason, no scientific basis for the table. It is simply given as an arbitrary table, and therefore just as good or just as bad as any other arbitrary table.

At that time I had some experiments carried on simply to test the correctness of my opinion that it was not desirable to heat wires so much as permitted by the new table. We keep the old rating for the present, but I do not say that we shall not change that rating. I do not say that if the proposed conference between the various interests sees fit to recommend, after due deliberation, one of the ratings, we should not adopt it. But at present we do not want to do so, for we think that that rating may possibly be changed when the danger of it is properly brought out. I then went to work looking up as many data as I could find and I plotted them on a sheet of paper which I have here. I have Prof. Forbes' tables for bare wire and for covered wire. They do not agree with anything else that I have been able to get. I had also plotted Mr. Kennelly's work for bare wire, black wire and concealed wire; also some experiments of our own, and from them reached the general conclusion that Professor Forbes' tables, which are based on scientific experiments, not made on wires, but on something else; are not correct. They do not give the proper carrying capacity for the wire at that particular temperature.

Now, as to the methods which I took to find out certain results, I suggested to one of our young men at the Institute, for a thesis, that it would be advisable to carry on some very interesting experiments from this point of view; we obtained seventy-five samples of wire, which we put through a careful test. The object of the test was to find out what strength of current passing through those wires for, say ten or fifteen minutes, would raise the temperature of the wire up to some definite point which we would readily recognize without measurement of the resistance or any guess-work. The first end point that was used was when a very small drop of water, inserted through a small hole in the insulation and put in contact with the copper would just boil; that was the first point. The next point was, when the slightest trace of visible smoke appeared. There were those two points. The seventy-five samples of wire were put through that particular test in this way; we took a 500-volt alternating circuit, connected it through a reactive coil to a welding coil. In the

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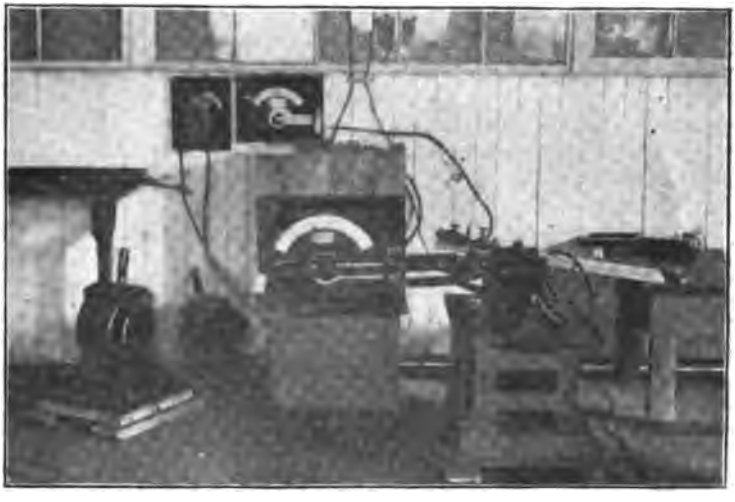
welding coil secondary we put the wire under test in series with a suitable ammeter and very slowly increased the current until the points were found. If the boiling point, which generally came first was reached too quickly, the current was reduced. The aim was to find the current which would just be sufficient when long continued, to give the indication. The wire was used in five foot lengths, and bent into a horizontal loop nearly circular. The room was as free from drafts as could be, and such care was taken that the results are as close as the rather uncertain end point will allow. Now, before showing you the curves, I want to refer to one thing which I have never seen pointed out:—it seems to me that in wiring, as in all engineering work, we ought to allow a safety factor. A bridge builder who in his calculations only allowed for the amount of weight he was



FIG, 1.—Arrangement of Apparatus for Heating Tests of Insulation.

going to carry over a bridge, would not be the man we would trust to build the Brooklyn bridge. We would want a man who would build a bridge that would stand not only the weight of the bridge cars but of the people in them, not only that of the people in them in ordinary times, but of the crowds who would be there in the case of a blockade, and we would want a margin beyond that. So in wires we want a margin—a margin over something—the only question that can be asked is over what? The reason for this margin is due to the fact that we cannot trust our fuses. Suppose we could trust to a fuse—we know that if we have a shunt motor, and start one of these great ventilating fans, that we have to use for a short time a great deal more current than the rated current for that motor, before we get the fan up to speed. We know too, that if our main line voltage is

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fluctuating, we have to put in a big fuse to take care of the fluctuations of the current. That means that the wire which presumably has been put in on the rating of the motor, has got to stand whatever can pass through the fuse that is used in practice. I say if that is the case, the rating table of the wires should have a safety factor, or else there should be some other way of getting the larger wire, as for example by specifying that the wire used should carry twice as much as the motors are rated for, or better still, carry the amount that the fuse will carry that we have to use in commercial operation. The curves I have are in rather a small shape for a room as large as this. Here (Fig. 2) is a sheet of paper. On it I have plotted the curves of Mr. Kennelly; one curve being the experimental curve, the double of which currents heat the wire up to 150° F. Along with that I have plotted the mathematical curve which Mr. Kennelly finds fits the experimental quite closely, and from which he calculated the safe carrying capacity of wire which has been taken as a basis for insurance work. The insurance table is rather inaccurate however, the values being given only to the nearest five amperes. In the table I have given the proper value as taken from the experimental curve and also the rating as adopted until January 10. Then I have plotted the double of that curve which is, of course, for a total rise of 75° F. These plots are for paneled wires. In order to show the difference between paneled wires and wires in the air, I am obliged to go to Mr. Kennelly's results and take from them his experiments on bright copper and black copper; then plotting them, in order to avoid confusion, at 80° C., I have plotted 80° C. rise with bright copper, black copper and paneled wire; the lower curve representing bright copper, the upper bare copper, the middle, paneled wire. The three curves keep together fairly well, showing that if we should take the panel wire curve as a basis for the rating in general we would not do any very great injustice to either the black copper or the bright copper. So I have simply taken it for granted that the paneled wire curve is correct enough for a basis.

The seventy-five samples which we tested up to the smoking point and the boiling point are plotted on this paper, and they give us this top curve. That curve represents the average of the smoking points of all sorts of wires that you can think of. There is thin underwriters', there is thick underwriters,' there is black line wire, thick and thin, there is rubber covered, thick and thin—all sorts. They all smoke just about at the same point. It does not make any difference whether you have the white underwriters' or the very heavy covered wire; if you watch carefully you will see smoke at just about the same current for the same sized wire. So you will agree with me, I think, that we may speak of the smoking point as a definite thing. The smoking point and the boiling point correspond at the smaller values and differ slightly at the upper values—5 or 10 per cent.

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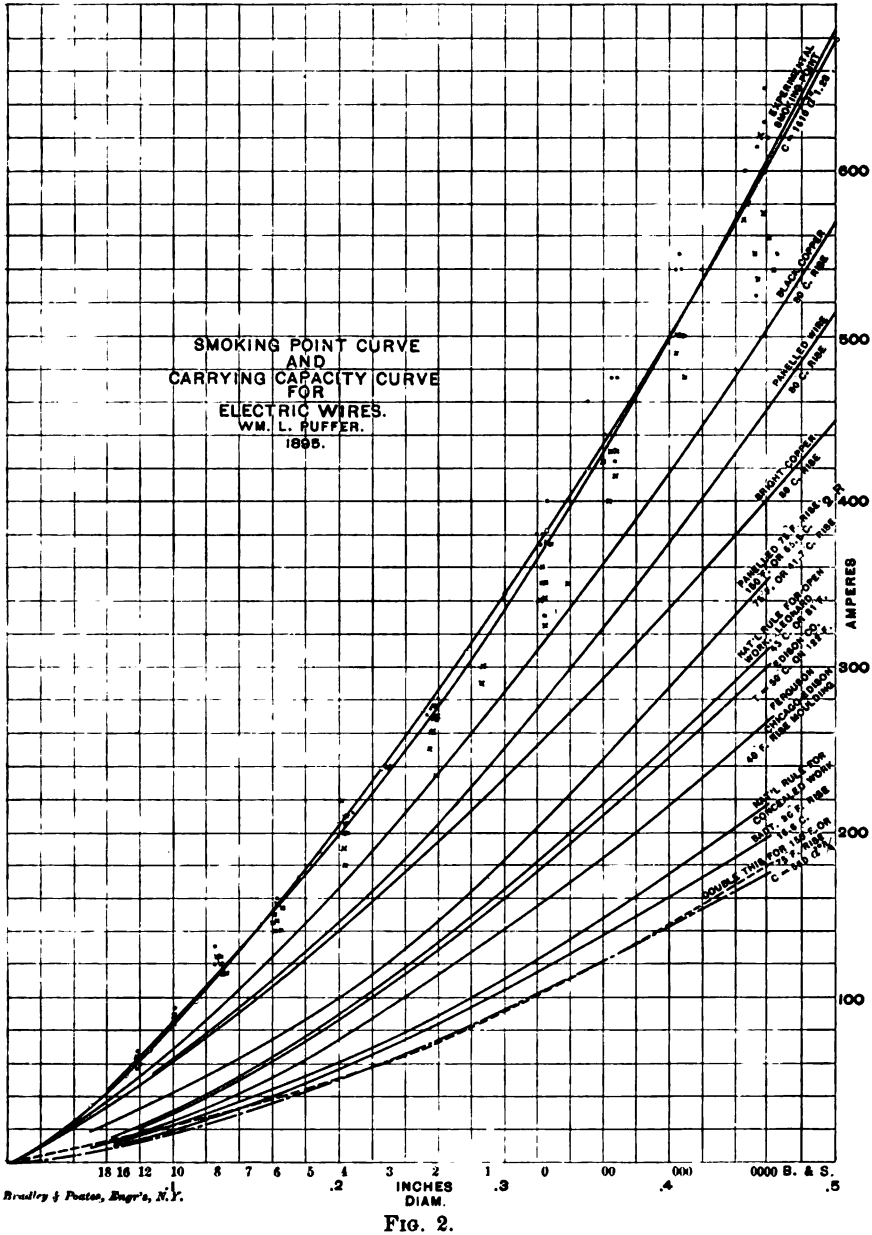

FIG. 2.

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Now as regards the safety factor—if we think of the injury to the insulating cover of our wire—and there is nothing else provided in the rules but rubber covered wire—our safety limit must be less than the point 150° F. where that rubber begins to spoil. Its safety point must not be over the 75° F. or 40° C. rise curve which I will call the safety valve curve, as it were, for rubber covered wire.

The open work rating of the present insurance rules—I mean the National, is a curve immediately under this 75° F. and almost up to it, no safety factor worth considering. I will admit that it would be all right possibly, provided it was for a constant current circuit and that the current could not increase over that particular value; but if we are obliged to use rubber wire for the sake of its insulating features we might as well save it, and if we do not want to save the rubber covering of the wire, let us put on something else. I have advised a factor of safety of 2 in our rating table of wires which is nothing else than Mr. Kennelly's original table which the insurance people have used up to the first of this year. And by the way, I should show you the 25 per cent. increase of the present rule which really rests on nothing whatever except arbitrariness. It is in here—here being the 150° F. point and this being the 25 per cent. increase. I have no objection to that rule except that if I double the current I heat the wire too much, and if that rule rested on some experimental data equally good, I should not object to it at all, and even now I do not object, except that it does not rest on anything particularly. We have nothing to go back to.

Professor Holman, of the Institute, to whom I showed this plot as I was leaving to take the train for New York, has sent me a letter which I received this morning in which he has given me a mathematical expression for this smoking point curve—he says is very close to it. The smoking current is 1,610 times the diameter of the wire to the 1.28 power, the diameter being in inches. The current then in amperes which will make any kind of insulated wire smoke can be calculated by taking 1,610 times the diameter in inches raised to the 1.28 power. Now the limiting rise of temperature of these observations made in ordinary air at a temperature of about 20 to 25° C. in about 80° C., and if we look at Mr. Kennelly's eighty degrees rise curves there is a discrepancy. Mr. Kennelly measured resistance and from that calculated the temperature. I am not prepared so say whether I believe that the resistance measurement actually expresses the true temperature of the wire itself. May it not be that the middle of the wire is much hotter than the outside, and consequently Mr. Kennelly's error be in one direction while our experiments must necessarily rest on an end point which is a little bit hotter and therefore giving an error in the opposite direction. Probably this is the reason for the discrepancy. If you will notice again you will see that, practically speaking, the original

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rating multiplied by 2 is the danger point of rubber. Twice that again is the point at which the rubber or any other insulation begins to smoke. Now it seems to me that a factor of safety of 4 is not too great; nor a factor of safety of 2 up to the point where you know you are going to spoil your wire insulation altogether.

It might not be uninteresting to read the table. I will read first the size of wire, Brown & Sharpe, then the ratings according to the experimental determination, then the ordinary insurance rule, then the 150 degrees, and then the smoke.

TABLE OF LIMITING CURRENTS FOR B. & S. GAUGE.

B. & S.	1	2	3	4
0000				
000	180			
00	149	175	360	630
0	123	145	298	519
1	103	120	246	438
2	86	100	206	372
3	72	85	172	319
4	60	70	144	273
5	52	60	120	237
6	45	50	104	207
7	39	45	90	178
8	34	35	78	155
10	29	30	68	134
12	23	25	58	127
14	17	20	46	87
	13	15	33	65
		10	25	48

No. 1. This column is taken from the published curves of Mr. Kennelly's experiments and express as nearly as could be taken from his curves those currents whose double would heat the wire up to the 150° F. point or 75° F. rise.

No. 2. This is the usual rating given in insurance tables before January 10th and is a rough approximation to the mathematical curve of Mr. Kennelly's.

No. 3. Taken also from Mr. Kennelly's curves and is a table of currents producing 75° F. rise or the danger point of rubber coverings.

No. 4. This is the table of smoking points of all kinds of insulations.

There is another point I want to bring up in connection with the general matter of insurance rules, and that is a question which I think is becoming quite important—and please understand that I do not stand as an alarmist in any way. I believe that electric lighting is a pretty safe thing. In connection with this insurance work I have seen some plants so bad that I do not see how they could run them at all. I have seen a plant so bad, and so fuseless in the proper places that when the engineer was asked if there was any trouble about running the dynamos, he said that sometimes the belts got to slipping a good deal, but if they got very bad he would hold them on with a stick for a little while, and then it would be all right again. The great spread of alternating current work is introducing danger, especially in mill work, where there are very high potential systems in use. The high potential is coming in the shape of transmitted current from a long distance, for use in the mill for light and power. For power work, of course, we can easily make it as safe as any power. But for lighting work, I think that the ordinary installation is a source of consid-

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erable danger which can be entirely removed by a device which I am a little afraid to suggest, although I believe in it thoroughly. I believe that where a transformer is used, receiving energy, say at three, four or five thousand volts, and transmitting the energy over a mill for lighting circuits at comparatively low voltages, that it is introducing a serious danger. Of course I admit, with everybody else, that converter insulation never breaks down. Nevertheless, suppose it did happen, and there are those who say it does now and then, we have the high voltages distributed over a hundred different circuits containing lamps and sockets designed for only the small voltage. Of course we know that any employee giving the system the slightest touch would have a shock even if the insulation was perfect, due to the electro-static capacity. I think the insurance rules ought to introduce another factor, and that is safety to life as well as safety from fire. I think there is something of an insurance nature in the demoralization of a fireman when he realizes that if he touches a wire he is likely to get an unpleasant sort of shock. Such a fireman is not half as good in putting out a fire as a man who will wade right in. Now, here is my suggestion: thoroughly ground the middle of your secondary wire. If you do that, your trouble all disappears. I look on it as the choice of two evils; I will take the lesser evil, and that lesser evil is grounding the middle of the secondary, putting a lesser strain on the insulation than by a ground either side, rendering it impossible for the high voltage to go over your mill, and then no one can get a greater shock from any part of the service than the voltage of the plant itself between the wire and ground. Suppose you have a 100-volt plant; if you ground in the middle, there is 50 volts alternating which is not a very serious matter. If you have a 3-wire transformer, it is nothing but 110 volts. If this is done, the electro-static charge element entirely disappears. You have no fear whatever of grasping your secondary wire at any particular point, and I must admit that I always take hold of a wire that I know to come from a transformer with very considerable dread; and that element would then disappear. The fire danger, I think, is comparatively small, and the fear of shocks in the minds of the firemen will instantly disappear. For in mill work, you know, the firemen are right around the premises at work, and they know just what is going to happen when they touch those wires, and from experience they will learn that there is nothing going to happen.

I think, gentlemen, I have taken altogether too much time under the pretense of opening the discussion on another man's paper by almost introducing one of my own. But I should be very glad to add anything that I can which I may have left out, or supply any information that I possess in this general matter that I have brought out and which I wish to have fully discussed, and especially the grounding of the secondary of transformers, which I believe most decidedly to be the proper thing.

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MR. A. E. KENNELLY:—Mr. President and gentlemen, I did not intend to say anything so early in the proceedings; but as there seems to be an unwillingness on the part of many present to bring forward their own remarks, I want to fill in the opportunity at least.

The broad question as to the desirability of having insurance rules revised, is, I think, very evident, since there seem to be so many different sets of rules in existence, and these not only differ in detail, but also radically, so that the rules by which a particular installation shall pass in one case or by one company, will not permit that same installation to pass or be admitted under the regulations of another company. The question as to how far this INSTITUTE ought to enter into an arrangement whereby such conformity of action can be obtained, is a little more difficult to determine. On the one hand it seems clear that from all commercial questions at least, the INSTITUTE should be careful to keep aloof, because a danger we all know exists that if the INSTITUTE enters into a question of endorsing a particular wire of Mr. A—. or the particular way of putting in a wire of Mr. B—. that there would be a continual demand that the INSTITUTE shall endorse the particular wires of Mr. X., Mr. Y. and Mr. Z. But in a case of this kind where injustice appears to be possible to a number of manufacturers, and to a number of persons who desire to make and install good work, it seems desirable that the INSTITUTE should at least lend a hand in settling a very difficult and very important matter. While of course, it is easy to put one's finger upon the weak points in various rules as we see them, yet I think we may perhaps be doing scant justice to bodies that have been doing a great deal of good work in the past; I mean these different insurance boards and the work that has been done by their advisers. I think there can be no doubt that if these insurance bodies with their rules and their inspectors had not been at work in the past, that electric lighting would have fallen into a great deal more discredit, and the art would have been much less advanced than it is at present. I think we owe therefore, a great deal of good to their efforts, even although their rules may be capable of improvement in detailed particulars. I think it is very important that any such system of rules should not state anywhere what good manufacturing should be. I maintain that every man should keep to his own business, and it is not the business of the fire inspectors or the fire insurance board to say what good electrical engineering, or good electrical manufacturing, or good electrical installation may be. The business of that board or those inspectors is to say what dangerous or false installation and work may be; and any system of rules, therefore, which should be arranged as a uniform system throughout the country should be careful to state what should not be done and not to try to define what should be done. If they do that, there will be far less

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danger of having to modify their rules every few months, as electrical methods multiply and change. The electrical manufacturer, contractor or engineer does not desire to state what fire hazard is, or its limitations, or its commercial capabilities. His duty is to endeavor to make the plant he has in hand as good as it can be made under the circumstances. Insurance rules would go beyond their natural limits altogether should they attempt to say what ought to be used, instead of simply saying what ought not to be used.

In regard to the detail question of the safe carrying capacity of wires, I think it is only fair to mention that Professor Forbes, when he tabulated such results as he possessed a good many years ago—I think it was about 1885—merely took such information, such experimental data as existed at that time, and put them into tabular form. He did not in any way declare that such data were reliable, but simply assuming them to be reliable gave the results to which those data pointed; and consequently the fact that in conformity with more recent developments, the tables that he prepared are not perfectly accurate, does not in any way detract from the merit of Professor Forbes' work. In fact he pointed out a great many things at that time which were and still are valuable, and which were new and important.

The question of how much margin should be left in different wires is an important one, because it always raises a question of economy; that is to say, the man who wants to put in a wire as cheaply as possible, wants naturally to put in as small a wire as shall be permitted to him under the rules; whereas, the man who has to take the fire risk wants to have that wire as large as possible, so that under no conceivable conditions the wire may become too hot. Therefore there must always be a conflict and a clash of opinion between those two representatives. When a large wire is put in, I mean a main or a sub-main, that large wire does not, it would seem, require to carry such a large excess of current as a small wire. That is to say, some accident may happen on a small wire by which an unduly large current may pass through it, or a motor may be on that wire which may require an unduly large current; whereas, all over a building a number of such accidents will not conspire, and therefore, a large main does not, I think, require so large a margin of safety as a small wire. But I agree with Professor Puffer that a margin of safety is desirable, and that we should not work up to the safety limit in putting in wire, particularly a small wire. The safety limit of a wire is, I think we will all agree, a wire which you can hold in the hand without discomfort. When a wire is so hot that you cannot hold it without either having a very thick epidermis or else a remarkable degree of Spartan equanimity, that wire is at the limit of safety. I think this temperature is reached by about 50 per cent. excess of currents over those given in the original table of Insurance Rules.

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I think then that a committee might be formed by the INSTITUTE, which should have the power to arrange some plan by which a general conformity of rules should be met all over the North American continent, to specify what bad practice should be, and what should be avoided, and that by such a plan we shall gain not only in simplicity but in security, and at the same time the manufacturer and the man who is putting in a plant shall not be harassed and hampered by needless complications.

THE PRESIDENT:—I see Mr. Woodbury is here. We would be pleased to hear from him upon this subject.

MR. C. J. H. WOODBURY:—Mr. President: The treatment by the speaker of the evening of the carrying capacity of wires is one which has a great deal of interest, and the ratio used in his factor of safety is one which I think deserves very careful attention. A factor of safety is an empirical multiplier, whose necessity in the mechanics of engineering is for the most part due to the variation between the hypothesis upon which the modulus of rupture is based, and the results of the precedents furnished by experience. Now, if a similar method of procedure will furnish a short cut to correct results in the treatment of the problems of the safe conductivity of wires, it will furnish a desirable innovation in many instances.

The suggestion of the last speaker is one which is somewhat attractive, and yet I believe that there is on the part of others something under way in that line in which when the details are presented, I think it will be found that arrangements have already been made for affiliating with the INSTITUTE OF ELECTRICAL ENGINEERS for the advice, cooperation and skill which they will be enabled to give.

The question is sometimes asked as to how far the underwriters should go as a matter of business policy on the promulgation of these insurance rules, which apply to the hazard of electricity, which is one of many hazards. An insurance policy is a contract of indemnity under conditions which are stated on that policy, and which must be construed according to the laws and decisions of the various states having jurisdiction. It may be considered that if a body of underwriters go beyond a certain point in the specifications of electric wiring or any one thing, they also assume responsibilities which may not have been contemplated in the original policy, and therefore there is a phase to this question outside or beyond that which is purely electrical or purely commercial, and that is the insurance side. I believe that it is through the insurance companies that the questions pertaining to the hazards of the transmission of large quantities of electrical energy, and their abatement, has been brought before the manufacturers and operators of electric plants, and that with the various opinions on the subject there is no doubt but that in the immediate future the results will be codified in rules which will be equitable and satisfactory to all of the various elements of the community which are interested in this subject.

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PROF. W. A. ANTHONY:—As I stated at the last meeting it was my object in reading that paper to provoke a discussion upon this matter and not so much to bring any particular aspect of it before the meeting. I felt that it was important that the electrical engineers should consider in some way the question of the insurance rules. I had no particular plan in mind. I did not suppose that the electrical engineers would go to work to frame rules for installations, but I wished to provoke a discussion which should show just where the engineering fraternity stood in this matter, and I am glad that so much has been done. This matter that has been brought before us to-night on the safe carrying capacity of wires alone, shows the importance of having this work done by engineers who understand the subject and who know just what the work means. Professor Puffer has brought together all the various experiments on the subject, has given us a number of new experiments of his own, and given us something on the safe carrying capacity of wires that we never had before. The fact that the insurance rules have been changed in this respect, without any warrant, without referring to any authority, seemingly entirely arbitrarily, enforces exactly the idea that I had in mind that it is the engineers who should decide upon such matters as these, and not the insurance companies. It seems to me that when such changes as these are made, the engineer should be consulted upon those changes, and I hope that some plan will be devised by which the engineers may have a voice in the matter.

The points that have been brought up here to-night are exceedingly important ones. The margin that should be allowed is a very important consideration, because safety fuses are uncertain in their action. The blowing of a safety fuse always takes time, and if a very large current is at once thrown upon a wire, a safety fuse may last long enough, before it blows, to allow the wire to become very highly heated, and this is especially the case where large wires are concerned, and where we are depending upon large safety fuses. I do not know that I quite clearly see the force of the remark of Mr. Kennelly on that point, that a large wire does not need the same margin of safety as a small one, because if we depend on safety fuses to protect a large wire, a large safety fuse takes so very much longer time to blow than a smaller one. If a current appears that is sufficient to injure the larger wire it is apt to remain upon that wire just so much longer time, unless an automatic magnetic break is used for cutting the current off. I can see, of course, that the large wire may not be as liable to be subject to a large current, because we may not have the combination of circumstances to occasion the great excess of current on the large wire. But that other point, that when we attempt to protect a large wire by a large fuse, that safety fuse may fail to blow and may carry the current for a long time over the wire, it seems to me makes it just as im-

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portant that the large wire should have as large a factor of safety as the small one.

MR. W. J. HAMMER:—At the last meeting I referred to the proposed call by the National Electrical Light Association for a joint meeting of the different organizations. I have here a list of those to whom it is proposed by that committee to extend the invitation. Although the formal invitation has not yet been extended, it will be very shortly, and assurances have already been given informally by a number of those parties that they will cooperate. It is proposed that this meeting should probably be held towards the latter part of September.

DR. C. T. HUTCHINSON:—I suggest that this discussion be ended. This is an entirely foreign matter.

THE PRESIDENT:—I think this has a bearing on the subject. The question under discussion was Professor Anthony's paper and also to see what action the INSTITUTE would take in pursuance thereof.

MR. W. J. HAMMER:—The organizations to whom it has been suggested that invitations be sent are, THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, The Underwriter's Association, the American Street Railway Association, the American Bell Telephone Company, the National Fire Chief's Association, the Western Union and Postal Telegraph Companies, the American Institute of Architects, the Inspection Department of the Associated Mutual Insurance Companies of Boston, and there are also several others which are under the consideration of the committee. It is also proposed to extend at that time a general invitation to any one interested either in insurance matters or in electrical installation throughout the country to send in to that meeting any objections or suggestions which they might have with respect to any of the rules which are at present being promulgated throughout the country. It is proposed that meeting should be held toward the latter part of September. It is hoped that such questions as Professor Puffer has brought up here tonight as to the carrying capacity of wires will receive very careful consideration.

Since the last meeting a prominent officer in the insurance interests sent me a letter in answer to some correspondence in which he said he was afraid there was considerable feeling among the insurance interests as to the attitude of the INSTITUTE as shown by our last meeting, and I think that if the gentleman had been present at the last meeting he would probably have felt differently about it. I do not think the position taken then by the members of the INSTITUTE was for anything but the general advancement of the subject and securing of the very best methods in construction and operation of electric work.

MR. J. I. AYER:—The relations of the insurance interests to the electrical interests in regard to wiring rules have been more or less strained for a number of years, in fact ever since the insurance people organized a department of electrical inspection,

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and it has been difficult to reconcile the differences and get harmonious action between the bodies representing the two interests —the insurance and the electric. That most of the trouble has been brought about by misapprehension there is no doubt, and by the lack of concerted action on the part of the electrical people. The National Electric Light Association representing the central station interests of the country has endeavored to effect harmonious relations and bring about the object which is now being sought, not only by the electrical people but I think, to some extent by the insurance people; that is a general code of rules which will suit all interests and which will perhaps be the result of the work of all interests; and I think it is only proper to emphasize the remarks made by Mr. Kennelly and Mr. Hammer in expressing the sentiments of the INSTITUTE so that there may not be a misconstruction put on this discussion by the insurance people of the country, but that they may understand the desire of the INSTITUTE is to harmonize with them—is not to oppose them but to work in harmony with them, and produce a universal set of rules. The insurance people in protecting their interests have apparently trodden on our toes, perhaps usurped our prerogatives as engineers, and this has been brought about wholly by the neglect of engineers to take care of their own interests.

In relation to the suggestion of Professor Puffer to ground the middle of the secondary coil of the transformer where high potential alternating currents are transformed and used for lighting and other purposes in mills—several years ago when our transformers at the ordinary pressures (1,000 volts alternating) were not as good as they are now, and would break down, some of us were much worried and had to suffer a great deal of anxiety by reason of the dangers people were subjected to by using these inferior devices which happily have disappeared. At that time I had occasion to design a protecting device, which, I think, would cover the difficulties he meets with, and that was an automatic switch which was operated by two solenoids, or either one of two, to open the main line of the secondary at the entrance of the building whenever a high potential current might get on the secondary wire. The solenoids were of sufficiently high resistance to prevent the leakage of but very few watts—they were connected directly across the mains, and the wire between was grounded—but with any excessive potential difference sufficient current would flow to actuate the magnets and open the circuit. The switch in opening could easily be arranged to permanently ground the secondary leads from the transformer, and leave the building cut out. These meet the difficulty without grounding the middle wire of the transformer, to which there are objections.

MR. FREMONT WILSON:—Professor Puffer's paper has interested me greatly. In regard to his criticism as to the factor of safety on motor wires differing from the factor of safety on

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electric light wires, my experience has been that there should be a great difference in the factor of safety. I would suggest that as we have a guest here this evening, a gentleman who has probably had more experience with motor service in this city at least, than any of the other members, that he be invited to give us his experience in regard to the factor of safety of motor lines, as compared to the factor of safety on electric light lines. I refer to Mr. Arthur Williams of the Edison company.

THE PRESIDENT:—The INSTITUTE will be pleased to hear from Mr. Williams.

MR. ARTHUR WILLIAMS:—After listening with much pleasure to the paper of Professor Puffer and the remarks which have been made, I really think that to present what I have learned in my own experience in a comprehensible form would require more time than it would be proper for me to take. I am hardly prepared to make any remarks that would interest the INSTITUTE, and therefore ask to be excused.

THE PRESIDENT:—I believe, gentlemen, that there is no other matter on our programme. I will encourage you by informing you of the fact that the envelopes are almost opened.

MR. C. O. MAILLOUX:—Some of the delay has been due to the fact that I have been feeling rather restive as the result of trying to follow the interesting discussion and do my work as teller at the same time. My excuse is that I am perhaps as much interested in this discussion as any member of the INSTITUTE, because my practice as an engineer brings me into as intimate contact with these rules as perhaps any other member of the INSTITUTE in this section and in various other parts of the country. Although I was unable to follow the whole discourse this evening because of my duties here as one of the tellers of this election, yet I followed it with as much as I could lend of attention. I am very glad that there has been the amount of expression of opinion that we have received this evening. I am glad to see that we are apparently aroused to the necessity of some action. I spoke with considerable feeling on the matter at the last meeting, and I perhaps could not do more at this session. I do feel, however, that I must reiterate the sentiment which I expressed, which is, that we ought not to be placed in the position of being dictated to in this matter in regard to what is proper, furthermore the rules of insurance inspection ought not to be such as to hamper progress in electrical installation. I know that in many instances in my experience I have found it impossible to introduce the reforms and improvements which were calculated to greatly enhance the character and value of the installation, and therefore, I feel strongly that there should be an end to all such methods that tend to retard the progresss of electrical work, and make us go back to prehistoric systems.

DR. C. T. HUTCHINSON:—It occurs to me that there would be a good deal of difficulty in telling just what margin of safety

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should be used in different cases. A factor of safety of 2 for which the double current brings the wire up to an unpleasantly warm point for the hand only, would be large, I should think, in many cases.

I did not altogether understand the reason for grounding the middle of the secondary. I should like very much if Prof. Puffer would explain it a little further when he speaks again.

Mr. Kennelly suggests changing the form of the rules entirely and substituting a series of "don'ts" for "do's." This seems to me fundamentally wrong, for if you formulate rules saying you shall not do certain things, you leave it entirely to the discretion of the inspector, in each case as to what shall be done. This would be one prohibited and many possible, some of which would be a great deal worse than the one proscribed. I should think that would open the door wide to the worst kind of work. I trust that Professor Puffer's paper will be published.

Mr. Mailloux:—Speaking from experience, I can say that the remarks made by the last speaker, if I understand him rightly, have a great deal of force. I do not think that it would be wise for any set of rules to undertake to go too clearly into what we ought to do. I think it would give us more latitude to do what we would like to do by placing the limitations in the form of negations, that is placing the limitations as to what we must not do. I think those limitations must be made as few as consistent with the conditions of absolute safety and general good work. Let the expert or specialist engineer attend to the rest. One of these limitations ought to be, for example, that Attix wire shall not be used except in a conduit for concealed work.

Dr. C. T. Hutchinson:—I cannot take the credit given me by Mr. Mailloux, this was Mr. Kennelly's suggestion. Mine is just the reverse.

The President:—Gentlemen, as I understand it, the question is whether it would be the part of wisdom for the American Institute of Electrical Engineers to prepare a code of rules for the safe installation of electric plants, which could in any way be called the American Institute of Electrical Engineers' Rules. I do not think that such work is our function. It seems to me that by so doing we would then put ourselves in the position in which we claim that the Board of Fire Underwriters are. We can criticise their rules; that is perfectly proper. But I do not think we want to make rules of our own. It is, however, intolerable for engineers to be put in the position of being told what is good engineering. This, I think, is something to which we should decidedly object, and I would be glad to see the Institute join with the parties referred to in a consideration of a code of rules. I would be sorry to see the Institute attempt to formulate a set of rules distinctively their own. I doubt very much if such rules would be accepted by the Board of Fire Underwriters, and any attempt to introduce them would make confusion worse confounded.

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PROFESSOR PUFFER:—There are two or three things I have noted as the various members have spoken. First, about the INSTITUTE rules—I think if the INSTITUTE attempts to go into the matter of rules it will come out in about the same way that the English Institution did. The English Institution attempted to go into rules, and met with the Phœnix Fire Office. The Phœnix Office was willing that the Institution should use any number of their rules they saw fit and modify them, provided it gave credit for the original rules which it declined to do, and the whole matter dropped through.

In regard to the matter of Prof. Forbes' experiments, I did not wish in any way to criticise the value of his work at that very early date when very few of us knew anything about electricity whatever. But I want to call attention to the fact that taken in the light of to-day his data were not right and rules based on those data could not be correct. Some error crept in, as it is evident, in all of his tables.

I would say, in connection with the inspection department, the element of judgment is admitted. We believe most decidedly in judgment, and at any time any contractor feels, and can show us that there is reason for believing that the modification of a rule or the adoption of a different method would be better, we are perfectly willing to allow and grant permission to do that very thing, which we would not allow in another case. For example we would admit, so far as fire is concerned, almost anything in an underground vault, where there was nothing but stone walls to burn, but if that same underground vault was a powder magazine we would not admit it. There, judgment is allowed. It is not allowed in the ordinary rules.

I would also say that I have a number of carrying capacity tables issued by different people, and I have striking illustrations of tables brought out by different authors and not properly credited, or at least that seems to be the inference, and in general the tables can be divided into two groups; one allowing a margin of safety of 1.5 to 2, and the other allowing scarcely any at all.

Some speaker has objected to the statement that rubber wire at the temperature of 150° F. is a dangerous thing. I did not intend to say that rubber wire at that temperature was a dangerous thing. What I say is this—if it is desirable to put the rubber tube on the wire, it is put there for some special reason that calls for rubber. Then if you do go to work and heat the wire inside the rubber to a point that would spoil that rubber, you are doing a wrong thing. While I do not object to spoiling the insulation in cases where the insulation is of no particular use, I should rather not have the insulation put there in the first place, for, of course we all know that rubber wire sufficiently overheated is a very dangerous thing. I have made a good many experiments on the actual burning of wires, and it is remarkable how rubber wire will act when suitably heated.

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About the margin of safety of big wires I agree with the speaker—I think it was Professor Anthony—that larger wires ought to have the same margin as smaller ones, for the danger comes when there is trouble in the system. For example, with a great dynamo in a plant distributing through great feeders, the danger comes when there is a short-circuit on the mains, of such a resistance due to the length of the arc that the current which may not be sufficient to blow the main fuses, will be sufficient to greatly overheat the insulation of the wires or even soften it.

About grounding the secondary—the reasons I believe in it are, first, to get rid of electro-static troubles; of course, that would be admitted, I think, anyway. Secondly, I have made a great many experiments on grounded transformers, and I have read with a great deal of attention the accounts of accidents that have happened through breaking down of transformers. I remember one where a transformer broke down during a sleet storm in the winter, simply due to the leakage of water into the case, and it was discovered accidentally and I immediately went there. I succeeded in burning 16 50-volt lamps in series between any lamp cord and the tin gutter of the green-house. At night, when it got cold, the ground entirely disappeared, and there was no inconvenience experienced. In the morning when the thaw came on again, we had the same trouble. These things could not positively happen with the middle of the secondary dead grounded, which fact in itself, is almost reason enough for the grounding. The worst thing that can happen is to blow a primary fuse.

In regard to the carrying capacity of the wire on motor load, I think personally that the carrying capacity on the motor load ought to have a greater margin if anything than on a lamp load, for the man that runs the motor is going to put in a fuse big enough not to trouble him under running conditions. I can, perhaps, best illustrate by a particular example, where a very big motor, several hundred horse power, was put in, supposed to take 60 amperes under full load. The wiring was figured on insurance rules for 60 amperes. It was found necessary on account of the starting current to use 180-ampere fuses. Now that wire calculated for 60 amperes was evidently protected, if such we can call it, by 180-ampere fuses. So that you will see that in that case there is quite a large demand on the safety factor of the rating of that particular wire. I know of a great many cases where motors at times are so heavily overloaded that they take in current three times their rating; that is, being rated for one, the current is often as great as 3. If the wire is selected for the rated current of the motor on the insurance rating of the wire, it is evidently carrying about 200 per cent. more than it ought to carry, and the protecting fuse is one that will allow at least 200 per cent. increase of current over the wire previous to the melting of the fuse itself.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 21st, 1895.

The Annual Meeting of the INSTITUTE was called to order by President Houston, at 8.10 P. M.

THE PRESIDENT:—The Secretary will read the minutes of the last stated meeting.

The Secretary read the minutes of the meeting of April 17th, and on motion of Mr. Mailloux they were accepted as read.

THE PRESIDENT:—Before asking the Secretary to read the minutes of the last Annual Meeting, the boxes of ballots are here, and the counting of the ballots is a task requiring considerable time, we will now either proceed to the election of tellers, or the Chair will appoint them, as you see fit. What is your pleasure?

MR. HAMBLET:—I move that they be appointed by the Chair.

[The motion was carried.]

The President appointed Messrs. Douglass Burnett and C. O. Mailloux as tellers.

THE PRESIDENT:—It is the duty of the Secretary to report the proceedings of Council for the past year. Mr. Secretary, you will please read the report of Council

The Secretary presented the following report:

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE YEAR ENDING APRIL 30TH, 1895.

As required by the Rules, the Council submits for the information of the membership a report of the work of the INSTITUTE during the past year.

The Council has held ten regular and one special meeting at which the average attendance has been eight.

The publication of the proceedings of the International Electrical Congress, which was undertaken by the INSTITUTE under a guarantee of four hundred subscribers at $3.00 each, was completed by the issuance of the volume in December last. An edition of one thousand copies was printed, the cost of which was $1,517.17. There have been sold to subscribers and dealers and furnished for review 520 copies from which has been realized $1,242.91. The amount of unpaid subscriptions is $174.00, leaving a present deficit of $100.26, represented by a stock of 480 books on hand.

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The demand for the book continues and the sale of the 480 copies on hand will eventually yield a profit. The expense of the publication was in excess of the estimated cost of $1,200, part of which was due to special editorial and translation work.

In June a suggestion was made to Council in a communication from one of the members, that the office of the INSTITUTE be removed to a down-town location. A special committee was appointed to consider the question, and after a thorough examination into the relative advantages of different locations, rooms were secured in the Havemeyer Building, which have been occupied by the Secretary and used for Council meetings and library facilities since Nov. 19th, 1894. This change involved an additional expense in rent of $250,00 a year, as it was still necessary that the INSTITUTE meetings should be held elsewhere, and the auditorium of the House of the American Society of Mechanical Engineers, which had been used for four years, seemed the most desirable place for the purpose. The files of the electrical and mechanical journals in the new location have proved much more accessible for the use of members, while visitors from various parts of the country have found the rooms of the INSTITUTE convenient and useful.

Mr. Edward Caldwell, Local Honorary Secretary at Chicago, resigned his office in September, owing to his removal from that city to New York. After securing the opinions of members residing in Chicago or its immediate vicinity, Mr. Bion J. Arnold was appointed as his successor. Papers have been read at both the New York and Chicago meetings according to the plan adopted last year and with very satisfactory results.

In view of the general interest in the engineering work at Niagara Falls, it was suggested to the Council by the Sub-Committee on Papers and Meetings, that the next General Meeting be held at that place. As it was found that the work would not be sufficiently advanced in May, it was thought desirable that a later date should be fixed upon and June 18th was chosen. A committee was subsequently appointed with power to postpone it if necessary not later than July 1st.

A Council rule has existed for several years restricting the numbers of transfers from associate to full membership to five at each meeting. As the delay caused by this limit led to a considerable amount of correspondence and explanations, and on account of the number of applications constantly accumulating, the number was raised to ten, beginning March 20th.

The Board of Examiners also recommended the adoption of a rule requiring that candidates for transfer should reach the age of 27 years before their applications for transfer from associate to full membership would be considered. The adoption of this rule was deemed advisable, for the reason that the experience in electrical engineering considered essential could not ordinarily be attained before that age was reached. The action taken was also in accordance with the practice of similar societies in other branches of engineering.

The total membership at the close of last year's report was 800, classified as follows:

Honorary Members	3
Members	235
Associate Members	562
Total	800
Associate Members elected	186
Total	986

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Total brought forward		986
The following have resigned during the year:		
A. F. CHRISTMAS, CHARLES LIEB, E. L. FRENCH, F. WAYLAND-SMITH, ARTHUR L. HOOPES, CHARLES A. BROWN, J. N. JAMES.		
Total resignations	7	
The following have died during the year:		
PROF. H. L. F. VON HELMHOLTZ, JOHN C. GEORGE, RUDOLPH EICKEMEYER, GEORGE B. SHAW, FRANKLIN P. LITTLE, CHARLES M. PAUL, GEORGE M. PHELPS.		
Total deaths	7	
Dropped from the roll on account of non-payment of dues	16	
Elected, but failed to qualify	12	42
		944
Leaving a total membership of 944 on April 30th, (a net gain of 144,) classified as follows:		
Honorary Members		2
Members		281
Associate Members		661
		944

The reports of the Secretary and of the Treasurer show in detail the financial affairs of the Institute at the close of the fiscal year:

SECRETARY'S BALANCE SHEET.

FOR THE FISCAL YEAR ENDING APRIL 30, 1895.

Dr.		*Cr.*	
To balance from 1893	$ 44 90	By cash to Treasurer	$10,602 22
Receipts for the year	10,572 52	Secretary's Balance on hand	15 20
	10,617 42		$10,617 42

ITEMIZED STATEMENT OF RECEIPTS AND EXPENSES OF THE INSTITUTE.

FOR FISCAL YEAR ENDING APRIL 30, 1895.

GENERAL ACCOUNT.

Receipts.		*Expenses.*	
Treasurer's Balance from previous year	$407 54	Office Expenses	$ 66 93
Secretary's " " " "	44 90	Office Fixtures	86 30
Sundry Receipts	29 95	Telegrams and Express	19 52
Entrance Fees	900 00	Stenography and Typewriting	712 50
Life Membership (James Lyman)	100 00	Stationary and Miscellaneous Printing	577 83
Past Dues	324 23	Postage	335 80
Current Dues	6,947 08	Messenger Service	55 43
Advance Dues	80 00	Salary Account	2,402 81
Electrotypes Sold	71 78	Meeting Expenses	332 21
Transactions Sold	506 90	Rent of Office and Auditorium	1,200 00
Transactions Subscribers	212 75	Engraving and Electrotyping	630 21
Advertising	219 32	Publishing Transactions	2,665 66
Received for Binding Transactions	27 50	Binding Transactions and Periodicals.	33 85
" " Badges	219 10	Paid for Badges	204 13
" " Certificates	42 10	Paid for Certificates	19 75
" " Congress-Book	891 81	World's Fair Expenses	10 43
[The amount of Advance Subscriptions in last year's report was $351.10.]		Congress Book	1,470 12
		Secretary's Balance to next year	15 20
		Treasurer's " " " "	186 28
Total,	$11,024 96	Total,	$11,024 96

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The outstanding current bills against the Institute, April 30, amounted to ...$	2511 29
Due from members.....	1847 88
Due from advertisers and others	295 71

The net gain in membership exceeds that of the previous year by seventeen. It will be seen, therefore, that while the financial stringency which has prevailed during the year has not checked the growth of membership, it has interfered with collections, and a large proportion of the amount due from members, is on account of lack of employment or loss of business. A fair proportion of this will, no doubt be paid, even should the present condition of business continue.

Respectfully submitted for the Council,

RALPH W. POPE,
Secretary.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 18th, 1895.

TREASURER'S REPORT.

FROM MAY 1, 1884 TO MAY 1, 1895.

GEORGE A. HAMILTON, TREASURER, in account with

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from May 1. 1894 .....$	407 54	
Received from Secretary, May 1, 1894 to May 1, 1895.....	10,602 22	$11,009 76

Cr.

Payments from May 1, 1894 to May 1, 1895, on warrants from Secretary, Nos. 522 to 617, inclusive.....$	10,823 48	
Balance to new account.....	186 28	$11,009 76
Balance on hand, General Fund, May 1, 1895.....		186 28

BUILDING FUND.

Balance as per last report .....$	850 00	
Interest accrued to May 1, 1895, 3 per cent., to May 14, 1892 and 2 per cent. thereafter.....	72 48	$922 48

Cash book and warrants herewith for audit. Vouchers are in the hands of the Secretary, to whom they are returned for filing after payment.

GEORGE A. HAMILTON,
Treasurer.

New York, May 18th, 1895.

THE PRESIDENT:—The Secretary has a minute to report from the Council relative to the date of the Niagara meeting.

SECRETARY POPE:—At the meeting of Council this afternoon

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it was decided to hold the General Meeting appointed to be held at Niagara Falls, on the dates of June 25th to 28th inclusive.

At the meeting of Council this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
ANDREWS, WILLIAM C	Student Electrical Engineering, Columbia College; residence, 162 Hicks St, Brooklyn, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
BEAMES, CLARE F.	Electrical Engineer, Gen'l Elec. Co., Schenectady, N. Y., residence, 63 W. 131st St., N. Y. City.	C. P. Steinmetz. Ernst J. Berg. H. G. Reist.
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St., N. Y. City.	E. S. Keefer. H. F. Albright. Geo. A. Hamilton.
DEWAR, JOHN THOMAS	Electrical Expert, Western Electric Co.; residence, 33 Rue Bouewijns, Antwerp, Belgium.	A. G. Inrig. F. R. Welles. Geo. B. Compagnie.
GHARKY, WILLIAM DAVID	Sup't Underground Cable Construction and Maintenance, Philadelphia Traction Co.; residence, Windsor Hotel, Philadelphia, Pa.	Minford Levis. F. Uhlenhaut, Jr. E. G. Willyoung.
HENDERSON, HENRY BANKS	Graduate Student, Cornell University; residence, 76 E. Buffalo St., Ithaca, N. Y.	Ernest Merritt. Harris J. Ryan. Fred'k Bedell.
HOGENTOREN, SYDNEY	Electrical Expert, The Varley Duplex Magnet Co.; residence, 1617 Avenue B, N. Y. City.	R. Varley, Jr. T. W. Varley. R. W. Pope.
JACKSON, THEODORE K.	Assistant to Sup't, Hyde Park Elec. Light and Power Co.; residence, 137 56th St., Chicago, Ill.	B. J. Arnold. L. K. Comstock. R. W. Pope.
ROLLER, FRANK W.	Electrical Engineer, with J. C. Machado, 203 Broadway, N. Y.; residence, 515 Clinton Avenue, Brooklyn, N. Y.	W. A. Anthony. E. P. Thompson. E. A. Merrill.
SIMPSON, ALEXANDER B.	Estimator, N. Y. Electrical Equipment Co., N. Y. City; residence, 125 2nd Place, Brooklyn, N. Y.	Aug. Noll. E. A. Merrill. W. A. Anthony.
WILCOX, NORMAN T.	Manager and Electrician, Seneca Light and Power Co., Seneca Falls, N. Y.	A. L. Rohrer. Geo. F. Curtiss. A. G. Mercer.

Total, 11.

The following associate members were transferred to full membership, their applications having been approved by the Board of Examiners:

ROMAINE CALLENDER,	Electrician, Decker Building, New York City.
J. DAY FLACK,	Electrical Engineer, 252 West 85th St., New York City.
F. R. COLVIN,	President, Interior Telephone Co., 203 Broadway, New York City.
RUSSELL ROBB,	with Stone & Webster, 4 Post Office Square, Boston.
V. M. BERTHOLD,	American Bell Telephone, 125 Milk St., Boston.
HERBERT LLOYD,	General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Drexel Building, Philadelphia, Pa.
HARRY HARTWELL BLADES,	General Superintendent, The Detroit Motor Co., 1343 Cass Avenue, Detroit, Mich.

Total, 7.

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The Secretary also read the following communication:

New York, May 21st, 1895.

To the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS:

Gentlemen:—At the Annual Meeting of the INSTITUTE held in New York City, May 15th, 1891, It was voted that $500.00 from the surplus of that year, together with the $350.00 constituting the Building Fund be invested, and that Treasurer George M. Phelps and Secretary Ralph W. Pope be appointed Trustees to take charge of the matter.

This amount was placed by the Trustees as a special deposit with the Mercantile Trust Co., and with accumulated interest now amounts to $922.48, as appears in the Treasurer's report.

By reason of the death of Mr. Phelps, there remains but one trustee, and it appears proper, under the circumstances, that this meeting should take action regarding the vacancy.

Yours truly,

RALPH W. POPE, Secretary.

THE PRESIDENT:—Gentlemen, what action will you take on the recommendation concerning the vacancy in the trustees caused by the death of Mr. Phelps.

MR. KENNELLY:—Mr. Chairman, I move that Mr. George A. Hamilton be appointed trustee.

[The motion was carried.]

THE PRESIDENT:—Will Professor Crocker please read the report of the Committee on the Indexing of Electrical Literature?

MR. HAMBLET:—Mr. President, before proceeding with the reading of that report I would suggest that the usual committee be appointed for auditing the accounts of the Treasurer and Secretary for the past year.

The chair appointed Messrs. Hamblet and Petty as an Auditing Committee.

PROFESSOR CROCKER:—Mr. President and Gentlemen: this report was submitted to the Council at its meeting this afternoon and was referred by the Council to the Annual Meeting of the INSTITUTE. It is a preliminary report of the Committee on Indexing Electrical Literature. It is not final in any sense whatever, and is simply given for the information of the INSTITUTE, and will be followed later by a more full report.

Professor Crocker then read the following report:

PRELIMINARY REPORT

OF THE COMMITTEE ON INDEXING ELECTRICAL LITERATURE TO THE COUNCIL OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

At the regular meeting of the Council held December 20th, 1894, a Committee on Indexing Electrical Literature was appointed, consisting of Prof. G. D. Shepardson, Prof. W. M. Stine, Mr. A. E. Kennelly, Mr. E. Caldwell, and Prof. F. B. Crocker, Chairman.

In view of the fact that it was practically impossible to get all the members of the Committee together, a circular letter was sent to each member, requesting answers to certain questions. The questions and answers of the five members of the Committee are given below.

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QUESTION 1. Is it advisable for the INSTITUTE to actually undertake the indexing of electrical literature?

The answers received substantially agree that while it is not incumbent upon the INSTITUTE to undertake the work, at the same time it is very desirable, and the INSTITUTE seems to be the best if not the only body to carry on the work permanently and authoritatively. The only question in regard to the INSTITUTE'S undertaking this matter is that of ways and means, which is considered under question 4.

QUESTION 2. Should the Index cover the past or current literature or both?

A. Four out of five members were of the belief that the past literature is the more important, and should be cared for first. The other member thought it advisable to attempt only current literature. The reason why past literature was considered more important is that current literature is fairly well covered by several indexes now being published.

(For example by the *Electrical World*, *Electric Power*, the Association of Engineering Societies and the *Fortschritte der Elektrotechnik*.)

QUESTION 3. Should the Index contain digest or notes, or merely titles of references?

A. All five answers agreed that the Index should contain brief notes as to the character or scope of the article.

This would seem almost essential, since a single line of description would save the looking up of probably seven-eighths of the possible references.

QUESTION 4. What means, particularly financial, can be devised to carry on the work of indexing?

A. The entire matter, of course, turns upon the answer to this important question and the Committee believes that the expense will be quite heavy, and probably much more than the INSTITUTE could bear with its present means. Two members of the Committee who are particularly qualified to estimate the cost of this work put the probable expense at $30,000 and $16,000 respectively. This includes the expense of compilation and publication of a reasonably complete index up to date. Two members of the Committee proposed raising the dues five dollars or two dollars and fifty cents, respectively, to meet the expenses. The other members doubt the propriety of this measure, as it would force many members of the INSTITUTE to pay for something which they do not require or use. The alternative plan would be to sell the Index by subscription to libraries and individuals, but it is doubtful if the number subscribed for would be sufficient to cover the large expense which the work would involve. The subscription, however, might be supplemented by the INSTITUTE bearing a certain amount of the expense, or by the cooperation of other societies in this country or abroad, or even by governmental aid—the United States Patent Office or the Smithsonian Institution. For instance, one member suggested that considerable expense might be saved by assigning a portion of the work to competent volunteers; for example, the indexing of a certain periodical could be assigned to an individual or an electrical school, without taxing their time very heavily, and it is probable that quite a fraction of the work could be done in this way. All the members of the Committee believe that an editor and two or three assistants would have to give their entire time to this work to make it successful—in fact, the salaries of these men would be the chief item of expense, since it is estimated by three members of the Committee that from three to four years would be required for the work.

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Thus it will be seen that the problem resolves itself into a simple question of sufficient means to carry on the work. From all other points of view, it seems to be the unanimous opinion of the Committee, and of others with whom it has consulted, that an index of electrical literature is very desirable and could be successfully and permanently carried on. Its value at the present time would be very great and in years to come it would be of incalculable benefit to to the electrical profession.

This report is merely given for the information of the INSTITUTE since your Committee does not consider that the time has arrived to formulate or propose definite recommendations in this matter. The Committee prefers to wait for further consideration of the question and would gladly welcome any suggestions from the members of the INSTITUTE.

F. B. CROCKER, Chairman.

THE PRESIDENT:—The committee has asked for suggestions on the part of the INSTITUTE. Those suggestions are now in order. I understand that this is only a preliminary report.

PROF. CROCKER:—Yes, sir. It is proposed, if possible, to hold a committee meeting at Niagara Falls, where we hope to get all the members together. It will be an opportunity that has not occurred so far, and is not likely to occur again, and we may be able as the result of such a meeting to formulate some definite plan.

THE PRESIDENT:—If the INSTITUTE can see its way, financially, to undertake work of this kind, it will certainly be greatly to the benefit of our particular study—electricity. It has occurred to me that it might be possible to get the English society, the Institution of Electrical Engineers, to join with us in the expense; or, a suggestion which the chairman of the committee threw out, might be utilized, not so much in the way of getting an appropriation from the government for carrying out this difficult work, but in the way of obtaining the aid of some army or naval officers. I remember that the indexing of the very extensive Journal of the Franklin Institute was largely done by a government officer, who was detailed by the United States government for the purpose. This is work that a skilled, educated man can do thoroughly, particularly if he be not hurried. I think it is quite possible that many an army or a navy man might be quite pleased to undertake work of this kind. The committee would receive any recommendations from the members of the INSTITUTE. If there are none, we will pass on to the next matter on the programme.

* * * * * *

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[After the discussion of Prof. Anthony's paper (see page 193), the business of the annual meeting proceeded as follows:]

THE PRESIDENT:—Are the auditors ready to report?

MR. HAMBLET:—I would say that the committee find the figures of the reports of the Secretary and Treasurer correct. We have endorsed the Treasurer's book in regular form, but will prepare the regular report and place it on file.

On motion the report was accepted.

The President appointed Dr. Cary T. Hutchinson and Mr. W. J. Hammer to assist in counting the ballots, and a recess was taken, subject to the call of the chair.

At 11.50 P. M., Vice-President Hamblet called the meeting to order, when the following report was submitted by the tellers Douglass Burnett and C. O. Mailloux and their assistants, W. J. Hammer and C. T. Hutchinson.

TELLERS' REPORT.

Total Votes Cast.....392.

FOR PRESIDENT.

Louis Duncan	334	T. A. Edison	1
F. B. Crocker	24	H. Ward Leonard	1
E. Thomson	8	F. A. Pickernell	1
A. E. Kennelly	8	Nikola Tesla	1
E. L. Nichols	6	C. P. Steinmetz	1
C. E. Emery	2	Joseph Wetzler	1
T. D. Lockwood	2	Blank	1
W. A. Anthony	1		
Total	392		

FOR VICE-PRESIDENTS.

A. S. Hibbard	343	C. R. Cross	3
M. I. Pupin	333	F. W. Jones	3
W. F. C. Hasson	307	E. W. Rice, Jr	3
C. P. Steinmetz	36	A. L. Rohrer	3
H. J. Ryan	21	Samuel Sheldon	3
A. E. Kennelly	19	A. J. Wurts	3
E. L. Nichols	11	W. S. Barstow	2
Alfred S. Brown	9	T. C. Martin	2
F. A. Pickernell	8	Jos. Wetzler	2
W. J. Hammer	7	W. A. Anthony	1
C. O. Mailloux	7	Frederick Bedell	1
W. M. Stine	6	Louis Bell	1
D. C. Jackson	5	O. T. Crosby	1
L. B. Stillwell	5	Louis Duncan	1
G. A. Hamilton	4	C. E. Emery	1
T. D. Lockwood	4	H. A. Foster	1
C. F. Scott	4	F. L. Pope	1
O. B. Shallenberger	4	G. D. Shepardson	1
W. D. Weaver	4	J. G. White	1
Gilbert Wilkes	3		

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FOR MANAGERS.

C. F. Scott	328	J. J. Carty	2
B. J. Arnold	322	C. L. Clarke	2
Carl Hering	322	Alex. Macfarlane	2
C. T. Hutchinson	292	Wm. Maver, Jr	2
H. A. Foster	32	E. W. Rice, Jr	2
T. C. Martin	31	H. A. Rowland	2
Samuel Sheldon	31	W. S. Barstow	1
F. A. Pickernell	21	P. Benjamin	1
Louis Bell	17	E. Caldwell	1
F. Bedell	15	C. Cuttriss	1
Wm. Stanley	15	F. DeLand	1
R. H. Pierce	13	W. E. Geyer	1
A. V. Abbott	10	C. D. Haskins	1
G. S. Dunn	8	E. J. Houston	1
H. V. Hayes	8	J. W. Lattig	1
D. C. Jackson	8	H. Ward Leonard	1
C. O. Mailloux	7	Aug. Noll	1
Jas. I. Ayer	5	H. F. Parshall	1
C. C. Haskins	5	F. L. Pope	1
J. W. Lieb, Jr	5	L. Stieringer	1
Jos. Wetzler	5	W. M. Stine	1
F. B. Crocker	4	L. B. Stillwell	1
S. D. Greene	4	Leonard Waldo	1
R. O. Heinrich	4	W. D. Weaver	1
P. Lange	4	J. G. White	1
A. L. Rohrer	4	A. J. Wurts	1
W. A. Anthony	3	Townsend Wolcott	1
Albert Schmid	3		

FOR TREASURER.

George M. Phelps	227	W. D. Weaver	4
George A. Hamilton	129	Joseph Wetzler	2
W. J. Hammer	16	T. C. Martin	1
F. B. Crocker	10		

Total 389

(Signed),

DOUGLASS BURNETT,
C. O. MAILLOUX,
Tellers.

New York, May 21st, 1895.

On motion of Mr. Mailloux, it was voted that the ballots cast for Mr. Phelps be declared void, and that the plurality of the remaining votes be accepted as determining the choice for Treasurer.

The chair then announced the election of the officers named in the report having the greatest number of votes, including George A. Hamilton, Treasurer.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Twelfth General Meeting.

Niagara Falls, N. Y., June 25, 26, 27 and 28, 1895.

The opening session of the twelfth General Meeting of the Institute was called to order by the Secretary at the Cataract House, Niagara Falls, on Tuesday June 25th, at 10.15 A. M. Two hundred and five members and guests were in attendance.

The Secretary announced that it had been the intention of Past-President Houston to attend the meeting, but he had been unexpectedly detained.

He then introduced the President-elect, Dr. Louis Duncan, of Baltimore, who on taking the Chair was greeted with a hearty round of applause.

President Duncan then introduced Hon. O. W. Cutler, Mayor of Niagara Falls, who addressed the Institute as follows:

Mr. President and Gentlemen of the American Institute of Electrical Engineers:—In behalf of the City of Niagara Falls, I extend to you a hearty and cordial welcome within our gates at this time. We have anticipated your coming with a great deal of pleasure and interest, believing as we do that it is fraught with great benefits to our city. You are doubtless all aware of the progress that has been made in the development of our unrivalled power, and of the proposed transmission and application of it by means of electricity, for which we are so largely indebted to your profession. I venture to say that you will see much in the line of your vocation to interest you while here, in visiting and inspecting our various enterprises, which, as I have already intimated, are of deep interest to the world at large, as well as of great importance to the material interests of our own locality. I trust that your stay here will be as pleasant as it will be interesting.

Again I welcome you and take pleasure in extending to you the freedom of our famous and romantic city. (Applause.)

President Duncan then presented Mr. Walter E. Harrington, of Camden, N. J., who read the following paper:

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 25th, 1895. President Duncan in the Chair.

PROPERTIES OF FUSE METALS WHEN SUBJECTED TO SHORT CIRCUITS.

BY WALTER E. HARRINGTON.

In the TRANSACTIONS of the INSTITUTE, May 1893, page 251 is a paper by Charles P. Matthews, "On the Behavior of Fuse Metals in Direct and Alternate Current Circuits." The paper deals quite exhaustively with the law established by Preece, Prof. Forbes and others, bearing on the relation existing between the diameter of fuse metals and the minimum currents required to fuse the metals, when sufficient time elapses for the fusion to occur.

The law as enunciated is $C = a\, d^{\frac{3}{2}}$ wherein

C = Current in amperes,

d = Diameter of wire in inches,

a = Constant depending on the metal.

The law is not rigorously true but can be depended upon very closely, particularly in the smaller diameters. In the larger diameters the law certainly does not hold true, as has been shown by different observers.

To be true and express the real relation, the constant a should be expressed as a function of d; and as far as my observation has led me, I think a is a linear function of d. It is not the purpose of the writer to elaborate on the various factors entering into the causes underlying the variability of fuse metals. The ground has been pretty thoroughly covered. [1]

1. "Safety fuses versus Magnetic Cut-outs," by W. E. Harrington, *Electrical World*, April 29th, 1893, vol. xxi, No. 17.
Paper read before American Street Railway Association, Milwaukee, October 1893. "Street Car Magnetic Cut-outs," by W. E. Harrington.

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On page 261 of Mr. Matthews' paper it is briefly mentioned that fuse metals rarely fuse in practice, under the conditions that the law as obtained demand.

Mr. Preece on short-circuit tests made by him writes in a very vague manner covering the results as obtained.

In the course of his professional work the writer has frequently had occasion to desire to know what current would flow through fuse metals on 500-volt short-circuit work. There being absolutely no literature on the subject, and the data to be obtained only by experiment, led to the following series of tests:

The tests were conducted in the power station of the Camden Horse R. R. Co., Camden, N. J., during August, 1894.

The testing room was about 30 feet away from the 'bus bars of the main station switchboard. No. 2 B. and S. gauge copper wires led from the 'bus bars to the testing table. At the switchboard the two leads were connected, one to the ground 'bus bar direct, the other through a 100-ampere knife-blade switch to the trolley side of a Westinghouse magnetic circuit breaker, whose range of adjustment was from 250 amperes to 500 amperes in 50-ampere steps. In the testing room the wires were arranged diagramatically, as show in Fig. 1.

A, was a special fuse block whose terminals were protected by oil, leaving 3″ of fuse in the atmosphere.

B, fuse metal whose fusing current on short-circuit was to be determined.

Paper read before the National Electric Light Association at its 17th Convenvention, Washington, D. C. Feb. 27, 1894. "Faults Incident to the Protection of Lighting and Power Circuits," by L. T. Stanley and W. E. Harrington.

Discussion of Mr. C. P. Matthews' paper "On the Behavior of Fuse Metals in Direct and Alternate Current Circuits." — TRANSACTIONS A. I. E. E., vol. x, page 266.

Catalogue of the Shawmut Fuse Wire Co., 161 High Street, Boston.

"Copper Fuses." Letter by B. S. Lanphear to the *Electrical World*, Jan. 19th, 1895, vol. xxv, No. 3.

Editorial Columns of the *Electrical Engineer*, Sept. 16, 1891, regarding the irreliability of fuses in alternating current work.

Proc. Roy. Soc. Dec. 22, 1887, Article on fusing currents and giving constants for different metals for Law $C = ad^{\frac{3}{2}}$ has the following values:—

Copper	$a =$ 10244
Aluminium	$a =$ 7585
Platinum	$a =$ 5172
German Silver	$a =$ 5230
Platinoid	$a =$ 4750
Iron	$a =$ 3148
Tin	$a =$ 1462
Alloy (Tin 1, Lead 2)	$a =$ 1318
Lead	$a =$ 1379

"Fuse results were determined by using six-inch lengths of wire."

"On the Heating Effects of Electric Currents," by W. H. Preece, *Proc. Roy. Soc.* April 3rd, 1884.

Reports British Association, 1882. Paper by Prof. Forbes.

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C, a C-S magnetic circuit breaker carefully calibrated throughout its range, not only for its adjustment, but also as well for 7, 14, 20, 30 and 40-turn coils. A Weston standardized ammeter was employed during calibration. Since the construction of the C-S magnetic circuit breaker is such that the adjustment depends only on weight and distance, the circuit breaker does not vary after use.

D, a 100-ampere knife-blade switch.

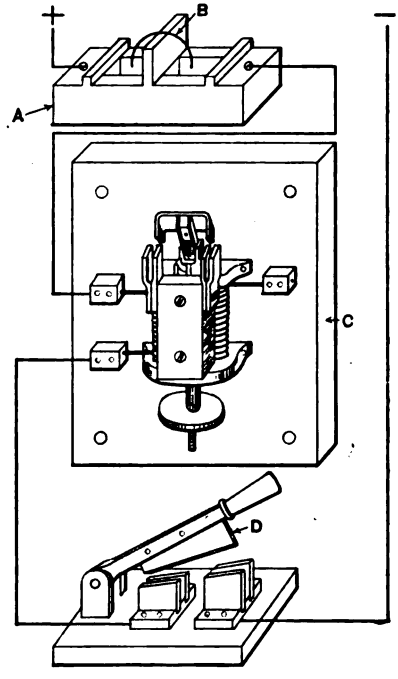

FIG. 1.

The fuse metals tested were placed in fuse block A and switch D thrown. This was repeated with the same size fuse metal a sufficient number of times to find the adjustment of the C-S magnetic circuit breaker which the current flowing would not open, also the adjustment at which the current flowing would open. The current which actually flowed would be somewhere between the two indications as obtained. The accompanying tables give the mean of the two readings. The tests were made during the middle of the day when the loads were light on the power

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station. A 200 K.W., G.E. 4-pole, and a 100 K.W.-Edison bipolar generator were running during the obtaining of the following data.

The sizes of fuse wires employed was such that the current flowing through them would not exceed 500 amperes, this being determined by the adjustment of the Westinghouse magnetic circuit breaker referred to before.

In the following tables the first column gives the size of wire in B. & S. gauge; the second column gives the circular mils.

The third column gives the mean of determinations as shown by the indications of the C-S magnetic circuit breaker.

The fourth column gives the constant B entering into the formula $C = B\,d^2$, where

C = current in amperes passing through the fuse metal on a short-circuit.

d = diameter of fuse metal in inches.

B = constant depending on metal and voltage of circuit short-circuit is made on.

The writer noticed that the values as obtained in the tests when compared with the circular mils of the wires tested showed a very close proportionality, showing that the fusing currents on short-circuits followed the law of the square times a constant.

TABLE I.

COPPER.

B. & S. Size Gauge.	d^2 C. M.	S. C. Amps.	B
30	100	37	380,000
29	126	44	350,000
28	159	62	390,000
27	201	80	398,000
26	254	116	456,000
25	320	140	437,000
24	404	225	556,000
23	509	300	589,000
22	642	370	576,000

Table I is for copper. While the constants B vary, especially as the sizes of the wire become larger, this variation is probably due to possible changes of conditions, such as differences of diameter, length of fuse metal, loads on the generators at the time tests were made and heating of the leading wires as the tests were being made. By averaging B the law for copper wires on 500-volt short-circuits could be stated to be:

$$C = 460{,}000\ d^2,$$

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or, expressed directly in terms of circular mils, the current which will flow in copper wires on 500-volt short-circuit will be:

$$C = \frac{C.\,M.}{1.9},$$

where C = current in amperes,
$C.\,M.$ = circular mils.

TABLE II.

ALUMINIUM WIRE.

Size B. & S. Gauge.	C. M. d^2.	S. C. Amperes.	B
24	404	200	500,000
21	810	290	358,000
20	1021	325	318,000

For aluminium the law for 500-volt short-circuit currents would be:

$$C = 392{,}000\ d^2.$$

$$C = \frac{C.\,M.}{2.6}.$$

There was one very pronounced peculiarity in the action of aluminium during the short-circuits; the metal seemed to burn longer and pieces of metal would come down after the explosion, still burning.

TABLE III.

STOCK (LEAD AND TIN) FUSE WIRE.

Size B. & S. Gauge.	Rating Fuse Wire Amperes.	C. M. d^2.	S. C. Amperes	B
24	1	404	50	125,000
21	3	810	115	156,000
19	5	1252	130	106,000
17	7	2048	230	118,000
15	10	3256	290	86,000

For fuse metal (ordinary commercial lead and tin alloy) the law for 500-volt short-circuit currents would be:

$$C = 118{,}000\ d^2.$$

$$C = \frac{C.\,M.}{9}.$$

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The dense heavy suffocating smoke attending the short-circuiting of lead and tin fuse metals was very pronounced and disagreeable.

Copper gave the best result as regard quantity of current per cross section of metal. This is shown in the formula for copper

$$C = \frac{C.\ M.}{1.9}.$$

where compared to the other metals the current per circular mil is a maximum, and that the amount of metal to disintegrate for a given current would be a minimum. In all the tests the behavior of the copper short-circuits were noticeably short and attended with a loud explosive report, with but little comparative flash.

One phenomena was noticeable when a cold surface, such as glass, was placed in the immediate path of the discharge; a finely deposited surface of light copper would present itself. This was unquestionably a case of condensation of the copper gases. While it may be argued that the law as enunciated by the writer, covering 500-volt short-circuit currents through fuse metals may not be rigorously true, still it certainly is as true relatively, as that of the law enunciated by Preece, covering the relation between minimum fusing currents and diameters of fuse metals.

In the use of the law for practical work where fuses had to be employed for cases beyond the values as determined by test, the values as obtained by extrapolation in every instance fulfilled the requirements, demonstrating the practical correctness of the law.

A few cases are cited wherein a knowledge of the law would be of practical value. Take railway work, elevator work, in fact, any case of varying power transmission, where if fuse metals are employed, the size of the fuse metal is governed not so much by the normal safe carrying capacity of the apparatus to be protected, as it is by the expected normal jumps of current the apparatus is designed for, and expected at times to carry. The standard 18 to 20-foot street railway equipments consisting of, say, two No. 3 or No. 14 Westinghouse motors, are usually protected by a piece of No. 14 B. & S. gauge copper wire which will normally fuse under a minimum current of approximately 168 amperes—according to Preece's law—whereas under a 500-volt short-circuit, if not prevented by some foreign means, such as feeder magnetic, or generator magnetic circuit breakers, a flow of approximately 2,000 amperes will ensue. Take as another illustration the lead and the tin alloy fuses employed by

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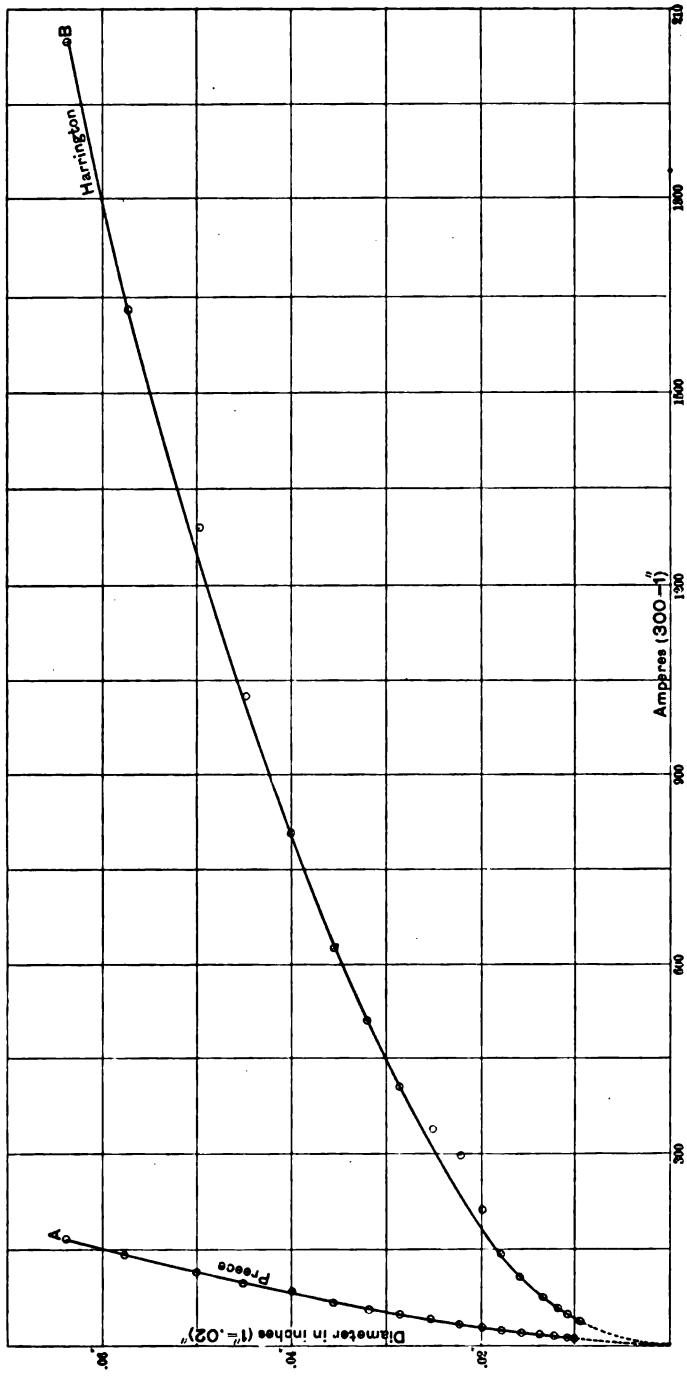

Fig. 2.

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the General Electric Company for their G. E. 800 equipments and rated to fuse on 100 amperes, will on a 500-volt short-circuit allow a flow of 3600 amperes for approximately .01 of a second, if not prevented by the opening of the power station magnetic circuit breaker. Further, with this latter type of fuse metal, the quantity of metal to disintegrate is so much greater, that usually more harm is done owing to the vicious character of the gas as regards conductivity, this usually establishing other grounds.

TABLE IV.

LAW.

B. & S. Gauge Copper.	Circular Mils.	PREECE.	HARRINGTON.
		Regular Amperes Rating.	Amperes Short Circuit.
30	100.5	11	39
29	126.7	12	44
28	159.7	14½	62
27	201.5	17	80
26	254.0	20	118
25	320.4	24	140
24	404.0	29	215
23	509.4	34	298
22	642.7	41	340
21	810.1	48	405
20	1021.5	56	510
19	1252.4	67	625
18	1624.3	84	812
17	2048.2	98	1024
16	2582.9	115	1291
15	3256.7	140	1625
14	4106.8	168	2053
13	5178.4	195	2589
12	6529.9	235	3264
11	8234.0	280	4117
10	10381.0	330	5190
9	13094.0	395	6547
8	16509.0	470	8000
7	20816.0	560	10000
6	26250.0	670	13000
5	33102.0	790	16000
4	41742.0	950	20000

At this point it is pertinent to refer to a phenomena accompanying the "blowing" of a fuse on a 500-volt short-circuit; that is, the destructive arcing following the disintegration of the fuse, maintained, of course, at the expense of the terminals. In the determination of the law $C = B\,d^2$ the after-arcing, was eliminated by using a protected terminal fuse block.

In a paper entitled "The Destructive Arcing of 500-Volt Fuses" read before the American Street Railway Association at Atlanta, Ga., October, 1894, by the writer, this matter is elaborated upon, and in brief shows that the results due to arcing, following the blowing of a fuse, may under short-circuit conditions

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be far worse than even the results attendant upon the passage of such momentarily great currents.

In Table IV, column 1 gives the size in B. & S. gauge of the copper wires; column 2 gives the circular mils; column 3 gives the minimum fusing current as determined by Preece's law, $C = 10244\ d^{\frac{3}{2}}$, and column 4 gives the fusing currents on 500-volt short-circuits as determined by the law, $C = 470{,}000\ d^2$, enunciated by the writer. Fig. 2 graphically illustrates the pronounced disparity of the two laws, showing the curves of currents for diameters: Curve A for Preece's law, and curve B for the law as discovered by the writer. The natural conclusion arising from a knowledge of the above data is that fuse metals are under no circumstances to be considered in the light or nature of a protection.

Discussion.

Dr. Leonard Waldo:—There is one matter that might be commented upon here. Aluminium is coming to play a more and more important part in electrical work, and a word of caution ought to be uttered in regard to the accurate use of the term. If you take a table such as given here, it is of great importance to know just exactly what that aluminium is. Assume that it is commercial aluminium and has a purity of 98 per cent., and that the balance of the ingredients are iron and silicon, which they probably are, and have a resistance about three times as great as that of pure aluminium under the same conditions, while the melting point is only slightly increased. You have, therefore, in questions of fuses, a very marked change in the relations of your aluminium. And aluminium wire that is sold is very often strengthened by the addition of small percentages of copper or nickel, or some of the other metals which are used to give strength to pure aluminium, and those wires pass also in the market under the term "aluminium" wire. I offer this comment as a caution in the use of the term "aluminium," and the use of aluminium wire under such conditions. If Mr. Harrington could furnish an analysis, or in some way define the term "aluminium wire," it would take its place then in terms with copper, which is pretty well understood, and with commercial lead and tin; but even in the case of lead and tin it would be well to indicate the brands, because they vary quite a good deal; and in all questions of resistance, the purity of the metal is of the first consequence.

Mr. Charles P. Steinmetz:—In listening to this paper I must confess that I have not quite understood what the writer intends to prove, and, therefore, I beg to be corrected if I am mistaken in my conclusions. But as I understand it, the writer connected

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fuses of various diameters and of various metals into a 500-volt circuit, closed the circuit through the fuses, and observed by means of a magnetic circuit breaker the maximum current which would flow through the fuse at the moment of closure of the circuit, before the fuse is blown.

Assuming even that the magnetic circuit breaker is a suitable means by which to determine instantaneous flow of current—which it is not, because the magnetic circuit breaker is like the fuse, an integrating apparatus, reacting upon the total amount of power passing through, and thus allowing a much larger current to pass for a very short time—assuming even this, then what do we have in reality? We have a 500-volt circuit closed by a fuse, and also by the leads which, compared with the fuse, may or may not be of negligible resistance. In such a circuit, as in any other circuit, the current flowing is equal to the E. M. F. divided by the resistance, and what the writer has observed is merely Ohm's law.

In consequence thereof, if the cross-section of the fuse is half as large, and the leads negligible, the resistance is twice as high, and thus the current half as large, and if a different metal of higher resistance is used, the current will be different also. But the constants derived in this way do not mean anything whatever. If, for instance, the writer had happened to use fuses of twice the length, all the currents, and thus all the constants given in the paper, would have been entirely different. So I do not see how any conclusions can be drawn from this investigation. It merely demonstrates Ohm's law, and that, we all knew before, holds true.

Another incidental remark I may make as to the proposition that a copper fuse is superior to any other fuse. This statement, I think, is based on a misunderstanding of the object of the fuse. A fuse is not in circuit only to open the circuit at a dead short-circuit. It is not even the best means for this. A magnetic circuit breaker, or any other circuit breaker, is far superior to guard against short-circuits, because fuses will not always open on dead short-circuit with unlimited power behind. The object of a fuse is to open the circuit, if the loads exceeds the carrying capacity of the lines, or the rated load. In this case, where the fuse is used in its proper place to guard against excessive load by cutting out the circuit at, say, 50 per cent over-load, the comparison between copper and lead fuses leads to quite different conclusions. Neither of these fuses will blow with such an explosion as on dead short-circuit. Both will be perfectly safe to open the circuit, but as soon as the load approaches fusing point, the copper fuse will be red hot, due to the high melting point of the copper, and thus liable to ignite dust or other combustible material, and set the building on fire. Thus the lead fuse is preferred to the copper fuse, not because it behaves better under a dead short-circuit, but because it opens the circuit and blows a

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a temperature below that which will ignite combustible material, and for this reason copper or any other metal with a high melting point is absolutely unsuitable for fuses, except in particular instances where the conditions are such that it can ignite nothing.

Dr. F. B. Crocker:—I had taken somewhat the same view of this subject that Mr. Steinmetz has given, only in a different way. It strikes me, as Mr. Steinmetz says, that this is simply an investigation of the maximum current reached under certain conditions, and it is not exactly what the author intended it to be. Any fuse would carry an infinite current for an infinitesimal period of time, or, to put it a little more practically, it would carry a very great current for a very short time. Now, if the author had closed the circuit for a definite period of time, that might have given certain results. Perhaps the circuit breaker acted in that way and gave a definite time, although, as Mr. Steinmetz says, that would depend on the amount of electrical energy, or the integral of the current which passed.

Furthermore, the question of exactly what a fuse is intended to do is another point to be considered. This "short-circuiting point" is a matter of some practical importance, although I do not think it is the definite and scientific quantity that is implied in the paper, because we want to protect coils of wire on dynamos or other apparatus from the effects of short-circuiting under certain conditions. If the fuse does not blow—and presumably the fuse is of lower current capacity than the wire of the machine to be protected—then it stands to reason that the wire will not be injured. Therefore, after all, in a practical common sense way, perhaps this test is a useful and important one. And often this is the object of the fuse after all.

But looking at the matter as a physical problem, it seems to me the questions involved are these:—that a fuse has a definite capacity for heat, and requires a certain number of calories to raise it to its fusing point; that amount being the product of its weight, specific heat and the temperature of fusion. That is the amount of heat required to raise it to fusing point, assuming that the action is so rapid that no heat is lost, which I think would be approximately true in this case. It is practically instantaneous, and the loss, I think, would be almost negligible. Now, a certain amount of electrical energy is required to produce that amount of heat, and that amount of electrical energy is just as definite as anything can possibly be. It is simply the electrical equivalent of that amount of thermal energy. We have a certain E. M. F. and a certain impedance to overcome, due to the resistance and the self-induction, and a certain time during which that current flows. Consequently, as a physical problem, we can investigate it by calculation. We can tell beforehand what current and what time would be required.

Mr. C. J. Reed:—It seems to me that from a physical standpoint I cannot agree with Dr. Crocker that it simply depends on

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a certain amount of heat generated, but the element of time and the surrounding conditions have all to do with it. The question as to whether the fuse will melt or not, appear to depend on whether there is a generation of heat in the wire at a rate exceeding that at which it is dissipated. If so, the temperature will continue to increase until the melting point is reached. If the conditions are such that with any given current, whether great or small, the heat is dissipated more rapidly than it is produced in the wire, then it will never reach fusion. It will reach a certain temperature and will not go beyond that. On the other hand, it is perfectly evident that if there is no opportunity for energy to dissipate, even an infinitesimal current would in the course of time fuse the largest wire. That seems to me very evident. If no heat can escape, even an infinitesimal current, theoretically, would in time heat the wire to its melting point; and, therefore, it seems to me that the only way any formula could be applied, would be under conditions in which the radiation must be absolutely the same for all temperatures of the wire, and in which no heat could escape through the terminals. That limits us practically to considering the central portion of a very long fuse, and one situated in a vacuum, or under other conditions, where the temperature of the surrounding space could be kept perfectly uniform. Then, as the temperature of the fuse rises, the difference between its temperature and that of the surrounding medium could be determined for any given temperature. But under ordinary conditions the most uniform that I can conceive of would be that of an exposure to air of uniform temperature. But this is impossible to get. If we compare, for instance, a fuse wire of very small diameter, say .001 inch, and another of a diameter of one inch, the small wire heating to its melting point, say for instance 2,000 or 1,500 degrees, if it is a wire that melts at that temperature, will heat only a very small amount of the surrounding air, whereas a wire one inch in diameter would heat a considerable thickness of the surrounding air, and consequently reduce its rate of cooling much more than a small wire would. It seems to me, then, that any formula we can get will be valueless unless we take into consideration the surrounding conditions.

So far as the comparison of copper wire and lead wire fuses is concerned, I cannot entirely agree with Mr. Steinmetz. I remember in the early days of electric lighting, when I did not know any better, I put up a plant in which I used copper wire fuses for electric lights on a 100-volt circuit. I used a No. 36 copper wire fuse about two inches long on every lamp. Later, when we got the Edison lead wire fuses in their cut-out boxes, I always noticed that the copper wire fuses when they went out never made any fuss, not the slightest noise of any kind, and only a very minute spark; while the lead wire fuses would invariably make a loud report and send a lot of melted metal around, which was likely to do damage; and I came to the conclusion that for

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this particular service the best kind of a fuse is one which will give the least amount of melted metal, and not the one that melts at the lowest temperature. It does not matter whether the metal melts at a low temperature or not, as the arc is very sure to heat it up to about the same temperature. Hence, the more metal the more danger.

PROF. W. A. ANTHONY:—There was one point in this paper that I did not fully understand. If I understood correctly, these experiments were all made with the same circuit connection, the same connection from the switch-board, and with the magnetic circuit breaker in circuit; and if I understood correctly, the experiments were made some 30 feet or so distant from the switch-board, and therefore leads of that length were necessary in order to reach the fuse. Now, under such circumstances, I can hardly see how the resistance of the connections could be negligible in comparison with the fuse. It would seem to me that the connections under such circumstances would be quite large, that the fuse would not be a large percentage of the whole resistance, and, therefore, that the amount of current that would flow would depend perhaps as much upon the connections, instruments, contacts, etc., in circuit, as upon the fuse itself, and that if these experiments were to be made with entirely different connections, with larger or shorter wires, that entirely different results would be reached, that a larger current would flow through the same fuse, because the amount of current that flows in this case, as Mr. Steinmetz says, is determined by Ohm's law; that is, by Ohm's law excepting the self-induction or impedance that comes in. And if we had a less resistance as a whole, no matter whether the fuse itself were of less resistance or not, then a much larger current would have passed through the same fuse. Now, unless the conditions were such that the connections were extremely small in comparison with the fuses, I cannot see why the result should not be as I have stated, and cannot see that the results given really show us anything of importance.

PROF. ELIHU THOMSON:—It seems to me that the question under discussion resolves itself into a question of what is the proper function of a fuse, whether it is to save the apparatus from an overload, or whether it is to save it only in the case of a short-circuit. It is conceivable that if the fuse is not to give any relief to an overload of say 50 per cent, but is merely to be active on short-circuit, then the copper fuse might perhaps be the best. But if the fuse is to act on, say, 50 per cent. overload, or some definite proportion of the normal load, then it strikes me that tin, lead, or fusible metal is undoubtedly the best, because we must not neglect the economy of the fuse. If, for example, we use a copper wire for a fuse, we must make it longer than the fuse metal in order that the heat of the fuse will not be conducted back to the terminals. Copper being such an excellent conductor of heat, it will, of course, if made short, deliver its heat rapidly

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to the terminals, and to get rid of any effect on the terminals, we would have to enlarge or lengthen out the copper. At the same time, if we lengthen it out and run it on a normal load at a considerable elevation of temperature so that it may fuse on, say, 50 per cent. overload, then we are wasting energy. We will have a great number of fuses which are running hot, and we know that a small wire, if of some length, can get rid of a considerable amount of energy. Again, with the tin and lead fuse, the conductivity for heat is low and the fuse runs at comparatively near normal temperature unless the overload comes. At that time it is ready to melt at a moderate elevation of temperature. If the function of the fuse is to save the apparatus in case of overload, then a soft metal must undoubtedly be the best.

Now what is the function of the fuse in the railway motor? Certainly not to save the apparatus in a case of short-circuit, because you cannot have a true short-circuit. You have a drop in the trolley line, you have a drop in the returns, and you have all through the connection a drop which, of course, would limit the current and remove any liability of any such values being reached as are stated in the paper. If the current did reach those high values for an instant, there would not necessarily be any bad result to follow, if the instant after, say .1 second or .01 second, all things are righted. Then it does not matter if we have just that momentary high flux of current. Now the fact is, that a car may be upon a grade, and for some reason or other it may be slipping down the grade. The motorman puts on the current rather briskly, and he may get for the moment 150 to 200 amperes. I have known that to occur. I have been on cars when tests were made, when the motors took that current for a time, when rotating slightly in the opposite direction current was suddenly put on. The fuse, which might have blown at, say, 50 or 60 amperes, did not, of course, blow under the conditions, but if the conditions had existed for any considerable time, the fuse would have blown and saved the apparatus. In other words, the motor could stand a high value of current for a short time without sustaining any harm. It seems to me that the practical question is the one which you have to consider in this connection.

Mr. Geo. W. Blodgett:—I take it the object of an investigation of this sort is one of two, either to establish a law, or to furnish a practical application. It seems to me that no formula can be devised in which a single constant would embrace all the conditions which are to be met, because, as has been said, the length of the fuse and the duration of time are both factors which determine to a degree the point at which it will melt. Perhaps I have overlooked it, but I see nowhere stated the length of the fuse which Mr. Harrington employed. Nor does he state definitely the time which elapsed between the closing of the circuit and the blowing of the fuse. Perhaps he does that in one or two cases, though I did not have an opportunity to read the

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paper beforehand. I think the experiment, to be complete, should state exactly the length of fuse employed and the time during which it was in circuit. A formula to be applicable to all cases should bring in those two factors, and it is rigidly true only when the exact conditions under which the test was made are reproduced. But we never have in practice exactly the conditions which we impose in the laboratory for an experiment of this sort, and if the object is to determine a law under theoretical conditions, then it should be distinctly stated what the conditions were, under which the test was made. But if it is to furnish a practical application, then as nearly as possible the conditions which exist in average practice should be reproduced, and it should be definitely stated what the conditions are under which the practical application is made in the test. I am sorry that Mr. Harrington did not state the length of the fuses and the composition of the alloys which he used, because varying the proportions of lead and tin, for instance, in the fuse which he employed, would vary quite considerably the melting point of the fuses. Some experiments made by the American Bell Telephone Company I believe developed this fact, that a current which was perfectly harmless for a short time, if continued through the coils of a telephone bell, for instance, for a considerable time, would destroy it. Therefore they found it necessary to provide against what they called "sneak" currents, that is, currents which for a short time will do no damage, but which continued a long time will do harm by a gradual rise of temperature, because, owing to the density and the number of turns in the coil of wire, the energy can not be dissipated as fast as it is communicated to the coil, and, therefore, a dangerous temperature results; and that should be taken into account in the application of a fuse to a particular purpose, how long the current can be continued without injury to the apparatus.

Mr. Allan V. Garratt:—What I was about to say was precisely what Prof. Thomson has said, and he has said it so much better than I could, that I will not go over the same ground. But I wish to say just this one thing more. It seems to me the most criticisable point of the whole paper is contained in the very last sentence, which I will read. "The natural conclusion arising "from a knowledge of the above data is that fuse metals are under "no circumstances to be considered in the light or nature of a pro-"tection." That is not a conservative statement. If the words "under no circumstances" were changed to "under some circumstances," it certainly would meet the approval of us all. There is probably not a man here who has not many times in his own experience seen fuse metals do precisely what they were intended to do. The point, I think, that is brought out in this discussion by Dr. Crocker, that we must first make up our own mind what we want fuse wire to do before we can find fault with it, is a very important one. We know in every machine designed

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what the bare wire will carry, and we are familiar with what will happen in the machine if an excessive current passes through it; and the machines are so designed that under the service for which they are intended they will dissipate the heat as fast as they are likely to get it under commercial conditions, and under most abnormal conditions the fuse acts.

Hence, although there is a great deal of value in this paper, yet its conclusion, I think, is erroneous, and not perhaps of the practical utility that its author intended.

MR. HARRINGTON:—As to the matter of the length of fuse, I think I mentioned in the paper its being three inches long, and the time of opening the circuit in these instances approximated .01 second. As to the use of fuses in railway work, where the fuse is intended to carry current for the jumps, and where you are liable to have the current as tabulated under short-circuit column on account of low line resistance, I think the law true in the majority of instances. It is a very noticeable fact in connection with railway work, that in climbing grades fuses very frequently blow when they are least wanted to blow; and yet if you put in a fuse large enough to carry the currents for that service, on a "ground" or "short-circuit," the current, while it may not rise to the quantity tabulated, still it will rise to such quantity as will by the torque or shock produced, cause a great deal of damage, which the protection of a circuit breaker will unquestionably prevent, as practice has proved.

That the use of fuses as a means of protection is not satisfactory is demonstrated by the use of magnetic circuit breakers on the Metropolitan railway in Chicago, and other large railways.

As to the conclusion concerning the non-protection that fuses afford, it is the occasional arising of this phenomenon that leads to their not being depended upon. For instance, very recently at the Broad Street station of the Pennsylvania Railroad, in Philadelphia, having Westinghouse generators, and using very large fuses, a short-circuit took place. The fuse did not blow. The generator was very badly injured and the crank-shaft broken, and considerable damage occurred. In the report that the engineers made, they recommended the use of magnetic circuit breakers, although before that time the same engineers had never considered circuit breakers as being advisable. It is the liability of these things to happen, owing to the properties that fuses have, that seems to point to their lack of reliability.

In the matter of the refinement of the law as enunciated, while it might have been conducted on a finer basis and results obtained which would be rigorously true, yet knowing that such a condition would not be attained, I was very careful to state all the facts as far as I was able to obtain them, aiming to bring out prominently the point that fuses have properties which have very seldom, if ever heretofore, been noticed and provided for. It has been my effort simply to bring these phenomena before you.

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MR. REED:—I would like to ask the gentleman if I understood correctly that the time in these experiments was .01 second.

MR. HARRINGTON:—Approximately that.

MR. REED:—In all cases?

MR. HARRINGTON:—Approximately that, yes; very closely

MR. REED:—In that case it does not seem to me, then, that this formula could be expected to apply in any way, because this is a formula which is intended to show the relation between the diameter of the fuse metals and the minimum currents required to fuse the metals when sufficient time elapses for fusion to occur. Now it is very evident that if you take two fuses of different diameters, under different conditions, and of the same metal, and if your current is just sufficient under those conditions to fuse the wire, it will not generally fuse both of them in the same time, being of different diameters; and hence to expect that they would all fuse in .01 second would be expecting something that certainly could not take place.

MR. HARRINGTON:—You are probably thinking about the law enunciated by Preece, where sufficient time elapses for fusion to occur. That law is: $C = a\,d^{\frac{3}{2}}$.

MR. REED:—Any time which you are going to allow for a given current to fuse the metals will not be the same for the fusion of different diameters, even of the same metal. The time will be such as is required for the increase of temperature to come up to the fusing point. You must remember that energy is being dissipated all the time and being developed all the time. The time when the fusing temperature will be reached will depend upon how much faster energy is being developed than it is being dissipated.

MR. HARRINGTON:—That is true, but in the law, as shown by Preece, time is eliminated. In fact, time drops out of the question when developed, and since time is ignored there, the actual conditions obtained in the tests were such that I have ignored the time. But I happen to know from other tests that it was about .01 second.

MR. STEINMETZ:—I wish to refer to what I believe is a misunderstanding of a statement made by Professor Crocker. Professor Crocker stated that the blowing of a fuse was merely a question of calories. Obviously that means the calories accumulated in the fuse, and this is the calories impressed upon it, in case of an excessive current, where the fusing takes place so quickly as to allow no time for noticeable radiation. Otherwise it is the difference between the calories impressed and the calories radiated by the fuse.

Now, with regard to the formula given in the paper, we can draw conclusions from the numerical values which plainly show their fallacy. It is stated there that the fuse in the Westinghouse car equipment allows 2,000 amperes to flow, and in the General Electric Co.'s equipment 3,600 amperes on a short-

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circuit. Now that means that at 500 volts impressed and by series parallel control, with the two motors of the car in series, the resistance of each Westinghouse motor is $\frac{250}{2000}$, or $\frac{1}{8}$ of an ohm, and the resistance of a General Electric Co.'s motor only $\frac{1}{15}$ of an ohm. Although both companies claim that their motors are very efficient, I do not think that either of them makes any claim to such low resistance as that.

MR. CARL HERING, Philadelphia:—In connection with the subject of fuse wires, a specimen which I have here may be of interest. It is a portion of the fuse wire of the high-tension, overhead lines of the famous Lauffen-Frankfort transmission plant, and was handed to me just now by Dr. Lobach, one of the engineers of that plant, and which he now presents to the INSTITUTE. It is a copper wire 0.1 mm. in diameter. The fuses were two metres long, stretched overhead between two poles, and consisted of two of these wires in multiple in each of the circuits of that three phase system. 200 H. P. at about 20,000 volts were transmitted through these fuses. It will be remembered that the center point of this three-wire system was grounded, and that these fuses acted as a cut-out to kill the line in case one of the three wires became grounded; an official test demonstrating their efficacy in a satisfactory manner was made before the plant was allowed to be operated.

MR. BLODGETT:—The shape of the fuse has also an important bearing on the temperature at which it will melt. If it is in the form of a flat strip, it will carry a higher current than if it is in the form of a solid rod or circular wire, particularly if it be intended to carry a large current. I saw an illustration of the conditions existing very nicely shown by the Electric Forging Company, in some experiments with their apparatus, in which an iron rod about one inch in diameter was heated to a bright red heat, and by regulating the current carefully it could be maintained at a constant temperature. That temperature was brought so high that while the outside of the rod was in a stable condition, owing to the dissipation of the energy into the surrounding air, the interior was melted, and would after a little time find for itself a vent through the outside shell, and the interior of the rod which was then fluid would run out, leaving a tube, while the outside would remain at a temperature sufficient to preserve its shape and integrity, showing that the dissipation of the energy under such conditions bears an important relation to the temperature at which destruction will occur. So in a large fuse, we should get a decidedly greater carrying capacity in the shape of a flat thin strip than we would if it were a solid circular or rectangular section.

CAPT. WM. BROPHY:—Nearly every point in this paper has been covered and discussed, except the concluding paragraph. I must say that I am nearly in accord with the writer in what he there says. I would simply amend it in this way: "The natural

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conclusion arising from a knowledge of the above data is that fuse metals are under *most* circumstances," etc. It has been my province to deal with fuse metals for the last twelve years. The functions which are required are prevention of an abnormal flow of current over the wires, thereby increasing their temperature to a dangerous point. I have only very recently tested commercial fuses—sent out and bought them—and I find that none of them come anywhere near doing what they are advertised to do. The current that they carry varies from 50 per cent. to 250 per cent. above what they are marked. Many of them have the same property as copper wire,—they heat; and I have maintained them in a red hot condition for five or ten minutes, or longer, if I so desire. I would like to see something substituted for the present commercial fuse, for a great many reasons. The men in charge of plants are apt to use fuse metals that are entirely too large, even if they did what they are supposed to do, protect the wires in which they are inserted. As they age, I find that their carrying capacity increases very rapidly. In fact, there are innumerable objections that could be stated to the use of fuse metal for the protection of wires and prevention of overheating the same, if time permitted.

Mr. Charles P. Steinmetz then read the following paper:

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25th, 1895. President Duncan in the Chair.

THEORY OF THE GENERAL ALTERNATING CURRENT TRANSFORMER.

BY CHARLES P. STEINMETZ.

The simplest alternating current apparatus is the alternating current transformer. It consists of a magnetic circuit, interlinked with two electric circuits or sets of electric circuits. The one, the primary circuit, is excited by an impressed E. M. F., while in the other, the secondary circuit, an E. M. F. is induced. Thus, in the primary circuit, power is consumed, in the secondary circuit a corresponding amount of power is produced, or in other words, power is transferred through space, from primary to secondary circuit. This transfer of power finds its mechanical equivalent in a repulsive thrust acting between primary and secondary. Thus, if the secondary coil is not held rigidly as in the stationary transformer, it will be repelled and move away from the primary. This mechanical effect is made use of in the induction motor, which represents a transformer whose secondary is mounted movably with regard to the primary in such a way that, while set in rotation, it still remains in the primary field of force.

We see thus that the stationary transformer and the induction motor are merely different applications of the same apparatus, comprising a magnetic circuit interlinked with two electric circuits. Such an apparatus can properly be called a "*general alternating current transformer*," and its equations in complex quantities are given in the following:—

The equations of the stationary transformer and those of the induction motor are merely specializations of the general alternating current transformer equations.

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The general alternating current transformer transforms between electrical and mechanical power, and changes not only E. M. F.'s and currents, but frequencies also.

Besides the magnetic flux interlinked with both primary and secondary electric circuit, a magnetic cross flux passes in the transformer between primary and secondary, surrounding one coil only, without being interlinked with the other. This magnetic cross flux is proportional to the current flowing in the electric circuit, and constitutes what is called the self-induction of the transformer. As seen, as self-induction of a transformer circuit, not the total flux produced by and interlinked with this circuit is understood, but only that—usually small—part of the flux which surrounds the one circuit without interlinking with the other, and is thus produced by the M. M. F. of one circuit only.

The common magnetic flux of the transformer is produced by the resultant M. M. F. of both electric circuits. It is determined by the counter E. M. F., the number of turns, and the frequency of the electric circuit, by the equation:

$$E = \sqrt{2}\,\pi\,N\,n\,M\,10^{-8}.$$

Where E = effective E. M. F.
N = frequency.
n = number of turns.
M = maximum magnetic flux.

The M. M. F. producing this flux, or the resultant M. M. F. of primary and secondary circuit, is determined by shape and magnetic characteristic of the material composing the magnetic circuit, and by the magnetic induction. At open secondary circuit, this M. M. F. is the M. M. F. of the primary current, which in this case is called the exciting current, and consists of an energy component, the magnetic energy current, and a reactive component, the magnetizing current.

In the general alternating current transformer, where the secondary is movable with regard to the primary, the rate of cutting of the secondary electric circuit with the mutual magnetic flux is different from that of the primary. Thus, the frequencies of both circuits are different, and the induced E. M. F.'s are not proportional to the number of turns as in the stationary transformer, but to the product of number of turns into frequency.

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Let, in a general alternating current transformer:

$$k = \text{ratio } \frac{\text{secondary}}{\text{primary}} \text{ frequency, or "slip,"}$$

thus, if:

N = primary frequency, or frequency of impressed E. M. F.,

$$k\,N = \text{secondary frequency,}$$

and the E. M. F. induced per secondary turn by the mutual flux has to the E. M. F. induced per primary turn the ratio k,

$k = 0$ represents synchronous motion of the secondary,

$k < 0$ represents motion above synchronism—driven by external mechanical power, as will be seen,

$k = 1$ represents standstill,

$k > 1$ represents backward motion of the secondary, that is, motion against the mechanical force acting between primary and secondary (thus representing driving by external mechanical power).

Let:

n_0 = number of primary turns in series per circuit,

n_1 = number of secondary turns in series per circuit,

$a = \frac{n_0}{n_1}$ = ratio of turns,

$Y_0 = \rho_0 + j\,\sigma_0$ = primary admittance, per circuit, where

ρ_0 = effective conductance,

σ_0 = susceptance,

$U_0 = r_0 - j\,s_0$ = internal primary impedance per circuit, where

r_0 = effective resistance of primary circuit,

s_0 = reactance of primary circuit,

$U_{11} = r_1 - j\,s_1$ = internal secondary impedance per circuit at standstill, or for $k = 1$, where

r_1 = effective resistance of secondary coil,

s_1 = reactance of secondary coil at standstill, or full frequency: $k = 1$.

Since the reactance is proportional to the frequency, at the slip k, or the secondary frequency $k\,N$, the secondary impedance is:

$$U_1 = r_1 - j\,k\,s_1.$$

Let the secondary circuit be closed by an external resistance r, and an external reactance, and denote the latter by s at fre-

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quency N, then at frequency $k\,N$, or slip k, it will be $= k\,s$, and thus:

$$U = r - j\,k\,s = \text{external secondary impedance.}^{1}$$

Let:

E_0 = primary impressed E. M. F. per circuit.
E_0' = E. M. F. consumed by primary counter E. M. F.
E_1 = secondary terminal E. M. F.
E_1' = secondary induced E. M. F.
e = E. M. F. induced per turn by the mutual magnetic flux, at full frequency N.
C_0 = primary current.
C_{00} = primary exciting current.
C_1 = secondary current.

It is then:

Secondary induced E. M. F.:

$$E_1' = k\,n_1\,e.$$

Total secondary impedance:

$$U_1 + U = (r_1 + r) - j\,k\,(s_1 + s);$$

hence, secondary current:

$$C_1 = \frac{E_1'}{U_1 + U} = \frac{k\,n_1\,e}{(r_1 + r) - j\,k\,(s_1 + s)}.$$

Secondary terminal voltage:

$$E_1 = E_1' - C_1\,U_1 = C_1\,U$$

$$= k\,n_1\,e\left\{1 - \frac{r_1 - j\,k\,s_1}{(r_1 + r) - j\,k\,(s_1 + s)}\right\} = \frac{k\,n_1\,e\,(r - j\,k\,s)}{(r_1 + r) - j\,k\,s_1 + s)}.$$

E. M. F. consumed by primary counter E. M. F.:

$$E_0' = -\,n_0\,e;$$

hence, primary exciting current:

$$C_{00} = E_0'\,Y_0 = -\,n_0\,e\,(\rho_0 + j\,\sigma_0).$$

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1 This applies to the case, where the secondary contains inductive reactance only, or rather that kind of reactance, which is proportional to the frequency. In a condenser, the reactance is inversely proportional to the frequency, in a synchronous motor under circumstances independent of the frequency. Thus in general we have to set: $s = s' + s'' + s'''$, where s' is that part of the reactance, which is proportional to the frequency, s'' that part of the reactance independent of the frequency, and s''' that part of the reactance, which is inversely proportional to the frequency, and have thus, at slip k, or frequency $k\,N$, the external secondary reactance: $k\,s' + s'' + \frac{s'''}{k}$.

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Component of primary current corresponding to secondary current C_1:

$$C_1' = -\frac{C_1}{a}$$

$$= -\frac{n_0 k e}{a^2 \{(r_1 + r) - j k (s_1 + s)\}};$$

hence, total primary current:

$$C_0 = C_{00} + C_1'$$

$$= -k n_0 e \left\{\frac{1}{a_2} \frac{1}{(r_1 + r) - j k (s_1 + s)} + \frac{\rho_0 + j k \sigma_0}{k}\right\}.$$

Primary impressed E. M. F.:

$$E_0 = E_0' + C_0 U_0$$

$$= -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{(r_1 + r) - j k (s_1 + s)} + (r_0 - j s_0)(\rho_0 + j \sigma_0)\right\}$$

We get thus, as the

Equations of the General Alternating Current Transformer,

of ratio of turns: a, and ratio of frequencies: k, with the E. M. F. induced per turn at full frequency: e, as parameter, the values:

Primary impressed E. M. F.:

$$E_0 = -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{(r_1 + r) - j k (s_1 + s)} + (r_0 - j s_0)(\rho_0 + j \sigma_0)\right\}.$$

Secondary terminal voltage:

$$E_1 = k n_1 e \left\{1 - \frac{r_1 - j k s_1}{(r_1 + r) - j k (s_1 + s)}\right\} = k n_1 e \frac{r - j k s}{(r_1 + r) - j k (s_1 + s)}.$$

Primary current:

$$C_0 = -k n_0 e \left\{\frac{1}{a^2} \frac{1}{(r_1 + r) - j k (s_1 + s)} + \frac{\rho_0 + j k \sigma_0}{k}\right\}.$$

Secondary current:

$$C_1 = \frac{k n_1 e}{(r_1 + r(- j k (s_1 + s)}.$$

Therefrom we get:

Ratio of currents:

$$\frac{C_0}{C_1} = -\frac{1}{a} \left\{1 + \frac{a^2}{k} (\rho_0 + j \sigma_0) [(r_1 + r) - j (s_1 + s)]\right\}.$$

Ratio of E. M. F.'s:

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$$\frac{E_0}{E_1} = -\frac{a}{k}\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)-j\,k\,(s_1+s)} + (r_0 - j\,s_0)(\rho_0 + j\,\sigma_0)}{1-\frac{r_1 - j\,k\,s_1}{(r_1+r)-j\,k\,(s_1+s)}}\right\}$$

Total apparent primary impedance:

$$U_t = \frac{E_0}{C_0} = \frac{a^2}{k}\,\{(r_1+r) - j\,(s_1+s)\}$$

$$\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)+j\,k\,(s_1+s)} + (r_0 - j\,s_0)\;(\rho_0 + j\,\sigma_0)}{1+\frac{a^2}{k}(\rho_0 + j\,\sigma_0)\;[(r_1+r) - j\,k\,(s_1+s)]}\right\}$$

Where:

$$s = s' + \frac{s''}{k} + \frac{s'''}{k^2}$$

in the general secondary circuit as discussed in foot note, page 4.

Substituting in these equations:

$$k = 1,$$

gives the

General Equations of the Stationary Alternating Current Transformer:

$$E_0 = -n_0\,e\,\{1 + \frac{1}{a^2}\,\frac{U_0}{U_1+U} + U_0\,Y_0\}.$$

$$E_1 = n_1\,e\,\{1 - \frac{U_1}{U_1+U}\} = n_1\,e\,\frac{U}{U_1+U}.$$

$$C_0 = -n_0\,e\,\left\{\frac{1}{a^2\,(U_1+U)} + Y_0\right\}.$$

$$C_1 = \frac{n_1\,e}{U_1+U}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\,\{1 + a^2\,Y_0\,(U_1+U)\}.$$

$$\frac{E_0}{E_1} = -a\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1-\frac{U_1}{U_1+U}}\right\}$$

$$U_t = \frac{E_0}{C_0} = a^2\,(U_1+U)\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1+a^2\,Y_0\,(U_1+U)}\right\}$$

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Substituting in the equations of the general alternating current transformer:

$$U = 0,$$

gives the

General Equations of the Induction Motor:

$$E_0 = -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 + j s_0)(\rho_0 + j \sigma_0)\right\}.$$

$$E_1 = 0.$$

$$C_0 = -k n_0 e \left\{\frac{1}{a^2 (r_1 - j k s_1)} + \frac{\rho_0 + j \sigma_0}{k}\right\}$$

$$C_1 = \frac{k n_1 e}{r_1 - j k \sigma_1}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\left\{1 + \frac{a^2}{k}(\rho_0 + j \sigma_0)(r_1 - j k s_1)\right\}.$$

$$U_1 = \frac{a^2}{k}(r_1 - j k s_1)\left\{\frac{1 + \frac{k}{a^2}\frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 - j s_0)(\rho_0 + j \sigma_0)}{1 + \frac{a^2}{k}(r_1 - j k s_1)(\rho_0 + j \sigma_0)}\right\}$$

Returning now to the general alternating current transformer, we have by substituting:

$$(r_1 + r)^2 + k^2 (s_1 + s)^2 = u_k^2,$$

and separating the real and imaginary quantities:

$$E_0 = -n_0 e \left\{\left[1 + \frac{k}{a^2 u_k^2}\Big(r_0 (r_1 + r) + k s_0 (s_1 + s)\Big) + (r_0 \rho_0 + s_0 \sigma_0)\right] + j\left[\frac{k}{a^2 u_k^2}\Big(k r_0 (s_1 + s) - s_0 (r_1 + r)\Big) + (r_0 \sigma_0 - s_0 \rho_0)\right]\right\}.$$

$$C_0 = -k n_0 e \left\{\left[\frac{r_1 + r}{a^2 u_k^2} + \frac{\rho_0}{k}\right] + j\left[\frac{k (s_1 + s)}{a^2 u_k^2} + \frac{\sigma_0}{k}\right]\right\}.$$

$$C_1 = \frac{k n_1 e}{u_k^2}\left\{(r_1 + r) + j k (s_1 + s)\right\}.$$

Neglecting the exciting current, or rather considering it as a separate and independent shunt circuit outside of the transformer, as can approximately be done, and assuming the primary

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$$\frac{E_0}{E_1} = -\frac{a}{k}\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)-j\,k(s_1+s)} + (r_0 - j\,s_0)(\rho_0 + j\,\sigma_0)}{1-\frac{r_1 - j\,k\,s_1}{(r_1+r)-j\,k\,(s_1+s)}}\right\}$$

Total apparent primary impedance:

$$U_t = \frac{E_0}{C_0} = \frac{a^2}{k}\,\{(r_1+r) - j\,(s_1+s)\}$$

$$\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)+j\,k\,(s_1+s)} + (r_0 - j\,s_0)\,(\rho_0 + j\,\sigma_0)}{1+\frac{a^2}{k}(\rho_0 + j\,\sigma_0)\,[(r_1+r) - j\,k\,(s_1+s)]}\right\}$$

Where:

$$s = s' + \frac{s''}{k} + \frac{s'''}{k^2}$$

in the general secondary circuit as discussed in foot note, page 4.

Substituting in these equations:

$$k = 1,$$

gives the

General Equations of the Stationary Alternating Current Transformer:

$$E_0 = -n_0\,e\,\{1 + \frac{1}{a^2}\,\frac{U_0}{U_1+U} + U_0\,Y_0\}.$$

$$E_1 = n_1\,e\,\{1 - \frac{U_1}{U_1+U}\} = n_1\,e\,\frac{U}{U_1+U}.$$

$$C_0 = -n_0\,e\,\left\{\frac{1}{a^2\,(U_1+U)} + Y_0\right\}.$$

$$C_1 = \frac{n_1\,e}{U_1+U}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\,\left\{1 + a^2\,Y_0\,(U_1+U)\right\}.$$

$$\frac{E_0}{E_1} = -a\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1-\frac{U_1}{U_1+U}}\right\}$$

$$U_t = \frac{E_0}{C_0} = a^2\,(U_1+U)\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1+a^2\,Y_0\,(U_1+U)}\right\}$$

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Substituting in the equations of the general alternating current transformer:

$$U = 0,$$

gives the

General Equations of the Induction Motor:

$$E_0 = -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 + j s_0)(\rho_0 + j \sigma_0)\right\}.$$

$$E_1 = 0.$$

$$C_0 = -k n_0 e \left\{\frac{1}{a^2 (r_1 - j k s_1)} + \frac{\rho_0 + j \sigma_0}{k}\right\}$$

$$C_1 = \frac{k n_1 e}{r_1 - j k \sigma_1}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\left\{1 + \frac{a^2}{k}(\rho_0 + j \sigma_0)(r_1 - j k s_1)\right\}.$$

$$U_1 = \frac{a^2}{k}(r_1 - j k s_1)\left\{\frac{1 + \frac{k}{a^2}\frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 - j s_0)(\rho_0 + j \sigma_0)}{1 + \frac{a^2}{k}(r_1 - j k s_1)(\rho_0 + j \sigma_0)}\right\}$$

Returning now to the general alternating current transformer, we have by substituting:

$$(r_1 + r)^2 + k^2 (s_1 + s)^2 = u_k^2,$$

and separating the real and imaginary quantities:

$$E_0 = -n_0 e \left\{\left[1 + \frac{k}{a^2 u_k^2}\Big(r_0 (r_1 + r) + k s_0 (s_1 + s)\Big) + (r_0 \rho_0 + s_0 \sigma_0)\right] + j\left[\frac{k}{a^2 u_k^2}\Big(k r_0 (s_1 + s) - s_0 (r_1 + r)\Big) + (r_0 \sigma_0 - s_0 \rho_0)\right]\right\}.$$

$$C_0 = -k n_0 e \left\{\left[\frac{r_1 + r}{a^2 u_k^2} + \frac{\rho_0}{k}\right] + j\left[\frac{k (s_1 + s)}{a^2 u_k^2} + \frac{\sigma_0}{k}\right]\right\}.$$

$$C_1 = \frac{k n_1 e}{u_k^2}\left\{(r_1 + r) + j k (s_1 + s)\right\}.$$

Neglecting the exciting current, or rather considering it as a separate and independent shunt circuit outside of the transformer, as can approximately be done, and assuming the primary

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impedance reduced to the secondary circuit as equal to the secondary impedance:

$$Y_0 = 0,$$

$$\frac{U_0}{a^2} = U_{11}.$$

Substituting this in the equations of the general transformer, we get:

$$E_0 = -n_0 e \left\{ 1 + \frac{k}{u_k^2} \left[r_1 (r_1 + r) + k s_1 (s_1 + s) \right] + \frac{j k}{u_k^2} \left[k r_1 (s_1 + s) - s_1 (r_1 + r) \right] \right\}.$$

$$E_1 = \frac{k n_1 e}{u_k^2} \left\{ \left[r (r_1 + r) + k^2 s (s_1 + s) \right] + j k \left[r s_1 - s r_1 \right] \right\}$$

$$C_0 = -\frac{k n_1 e}{a u_k^2} \left\{ (r_1 + r) j k (s_1 + s) \right\}.$$

$$C_1 = \frac{k n_1 e}{u_k^2} \left\{ (r_1 + r) j k (s_1 + s) \right\}.$$

If:

$E = a + j b =$ E. M. F., in complex quantities, and

$C = c + j d =$ current, in complex quantities,

the power is:

$$P = | E, C | = E C \cos (E, C) = a c + b d.$$

Making use of this, and denoting:

$$\frac{k n_1^2 e^2}{u_k^2} = w$$

gives:

Secondary output of the transformer:

$$W_1 = | E_1 . C_1 | = \left(\frac{k n_1 e}{u_k}\right)^2 r = k r w.$$

Internal loss in secondary circuit:

$$W_1^1 = c_1^2 r_1 = \left(\frac{k n_1 e}{u_k}\right)^2 r_1 = k r_1 w.$$

Total secondary power:

$$W_1 + W_1^1 = \left(\frac{k n_1 e}{u_k}\right)^2 (r + r_1) = k w (r + r_1).$$

Internal loss in primary circuit:

$$W_0^1 = c_0^2 r_1 = \left(\frac{k n_1 e}{u_k}\right)^2 r_1 = k r_1 w.$$

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Total electrical output plus loss:

$$W^1 = W_1 + W_1^1 + W_0^1 \quad = \left(\frac{k\, n_1\, e}{u_k}\right)^2 (r + 2\, r_1) \;= k\, w\, (r + 2\, r_1).$$

Total electrical input of primary:

$$W_0 = |\, E_0,\; C_0 \,| = k \left(\frac{n_1\, e}{u_k}\right)^2 (r + r_1 + k\, r_1) = w\, (r + r_1 + k\, r_1).$$

Hence, mechanical output of transformer:

$$W = W_0 - W^1 = w\, (1 - k)\, (r + r_1).$$

$$\text{Ratio: } \frac{\text{mechanical output}}{\text{total secondary power}} = \frac{W}{W_1 + W_1^1} = \frac{1 - k}{k} = \frac{\text{speed}}{\text{slip}}.$$

Thus:

In a general alternating transformer of ratio of turns a, and ratio of frequencies k, neglecting exciting current, it is:

Electrical input in primary:

$$W_0 = \frac{k\, n_1^2\, e^2\, (r + r_1 + k\, r_1)}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Mechanical output:

$$W = \frac{k\, (1 - k)\, n_1^2\, e^2\, (r + r_1)}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Electrical output of secondary:

$$W_1 = \frac{k^2\, n_1^2\, e^2\, r}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Losses in transformer:

$$W_0^1 + W_1^1 = W^1 = \frac{1\, k^2\, n_1^2\, e^2\, r_1}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Of these quantities, W^1 and W_1 are always positive; W_0 and W can be positive or negative, according to the value of k. Thus the apparatus can either produce mechanical power, acting as a motor, or consume mechanical power, and it can either consume electrical power or produce electrical power, as a generator.

At:

$k = 0$, synchronism, $W_0 = 0$, $W = 0$, $W_1 = 0$.

At:

$0 < k < 1$, between synchronism and standstill.

W_1, W and W_0 are positive, that is, the apparatus consumes electrical power W_0 in the primary, and produces mechanical power W and electrical power $W_1 + W_1^1$ in the secondary, which

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is partly— W_1^1—consumed by the internal secondary resistance, partly— W_1—available at the secondary terminals.

In this case it is: $$\frac{W_1 + W_1^1}{W} = \frac{k}{1-k},$$

That is, of the electrical power consumed in the primary circuit — W_0—a part W_0^1 is consumed by the internal primary resistance, the remainder transmitted to the secondary, and divides between electrical power $W_1 + W_1^1$ and mechanical power W in the proportion of the slip, or drop below synchronism—k—, to the speed: $1 - k$.

In this range, the apparatus is a motor.

At:

$k > 1$, or backwards driving,

$W < 0$, or negative, that is, the apparatus requires mechanical power for driving.

It is then: $$W_0 - W_0^1 - W_1^1 < W_1,$$

that is: the secondary electrical power is produced partly by the primary electrical power, partly by the mechanical power, and the apparatus acts simultaneously as transformer and as alternating current generator, with the secondary as armature.

The ratio of mechanical input to electrical input is the ratio of speed to synchronism.

In this case, the secondary frequency is higher than the primary.

At: $K < 0$, beyond synchronism.

$W < 0$, that is, the apparatus has to be driven by mechanical power.

$W_0 < 0$, that is, the primary circuit produces electrical power, from the mechanical input.

At:

$$r + r_1 + k\,r_1 = 0, \qquad \text{or:} \qquad k < -\frac{r + r_1}{r},$$

the electrical power produced in the primary becomes less than required to cover the losses of power, and W_0 becomes positive again.

We have thus: $$k < -\frac{r + r_1}{r},$$

consumes mechanical and primary electric power; produces secondary electric power.

$$-\frac{r + r_1}{r} < k < 0,$$

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consumes mechanical, and produces electrical power in primary and in secondary circuit.

$$0 < k < 1,$$

consumes primary electric power, and produces mechanical and secondary electrical power.

$$1 < k,$$

consumes mechanical and primary electrical power; produces secondary electrical power.

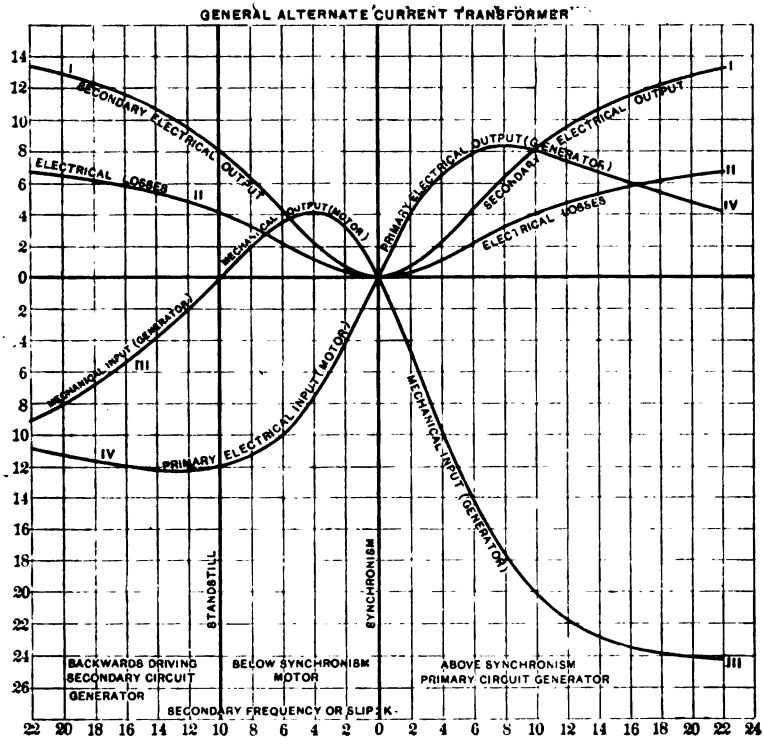

FIG. 1.

As an instance, in Fig. 1 are plotted, with the slip k as abscissae, the values of:

secondary electrical output	as curve I,
total internal loss	as curve II,
mechanical output	as curve III,
primary electrical input	as curve IV,

for the values:

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$$n_1 e = 100,$$
$$r_1 = .1,$$
$$s_1 = .2,$$
$$r = .4,$$
$$s = .3;$$

hence:

$$W_1 = \frac{16{,}000\ k^2}{1 + k^2},$$

$$W_0^1 + W_1^1 = \frac{8{,}000\ k^2}{1 + k^2},$$

$$W_0 = \frac{4{,}000\ k + (5 + k)}{1 + k^2},$$

$$W = \frac{20{,}000\ k\ (1 - k)}{1 + k^2}.$$

Discussion.

Dr. M. I. Pupin:—I was given this very interesting paper a few days ago, but unfortunately I lost it and have not had a chance to look over it carefully again, and it is a paper that requires very careful study before any comment can be made upon it. It seems to me that from the viewpoint of the comprehensiveness of the subject with which the paper deals, the author accomplishes just what he intended. That is, to give in a very small compass the general theory of the alternating current machinery that is used to-day in commercial work, and he does it in a most elegant way. But it is elegant on account of its simplicity. This simplicity is made possible by the introduction of a peculiar method of accurate analysis which Mr. Steinmetz has worked out all by himself.

There is another point which recommends this general treatment of current transformers, namely: not only is the method a simple one, but it is easily translated into graphical methods. We can actually take these equations and by pencil and ruler transfer their physical meaning to paper by means of simple lines and curves.

I saw a machine at the Frankfort Exhibition, which, if I remember correctly, was constructed by Schückert. It would give you an alternating current, a two-phase direct current, a three-phase current, or anything else you wished, and for that reason it was called the "maid-of-all-work." This theory of alternating current machinery which Mr. Steinmetz has given us may be called the "maid-of-all-work" in alternating current machinery, because it gives information not only about the alternating current transformer, but also about the alternating current generator and alternating current induction

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motor. Perhaps Mr. Steinmetz will some day construct a machine which can be used at the same time as an alternating current generator, an induction motor, transformer, or anything else that occasion may demand. It is a very original and very interesting piece of work that he has presented in this paper.

There is one thing though that Mr. Steinmetz has not mentioned, and that is that it is an ideal theory. I mention this because some time ago I had the pleasure of presenting somebody else's paper before this INSTITUTE. Having been called upon to present the paper, I studied it carefully, and fell in love with it more or less, and I feel that way still. But Mr. Steinmetz was there, and he thought because I praised the paper, he ought to take the other side, so as to make the evening pleasant and interesting. The fault he had to find with the paper was that it was too theoretical, and it was too mathematical. [Laughter.] But that was not anything so very serious from an engineering point of view, because there are a great many engineers who are very fond of mathematics. But there was a more serious defect in the paper still, according to Mr. Steinmetz, and that was that the paper was misleading because it gave theoretical results concerning the induction motor, which results were deduced from an hypothesis which never occurs in practice, and that is that there was no magnetic leakage; and if there was any, that this magnetic leakage was not affected by the load. Now I have the same fault to find with Mr. Steinmetz's paper. That is, that he has not taken into account the magnetic leakage. He could not do that, of course, because that is impossible, but he has not stated that he has not taken account of the magnetic leakage; and therefore I think that in that respect the paper is somewhat misleading.

MR. STEINMETZ:—Coming to the last point first, I think Dr. Pupin has misunderstood me. The magnetic leakage is considered in the paper, and very completely. Not only the primary magnetic leakage, but the secondary magnetic leakage also. It is what I call and introduce here as the magnetic cross flux, that is that magnetic flux produced by one circuit and interlinked with this circuit only, but not interlinked with the other circuit. Its coefficients are denoted here by "s" and "s_1," primary internal reactance, and secondary internal reactance. This magnetic leakage is proportional to the current because reactance is of the nature of a resistance, and is treated as such in my paper. The only error which can come in here is the lack of proportionality between the magnetic cross flux and the current producing it, that is, the variation of the ohmic reactance. However, this magnetic leakage is a cross flux in a circuit consisting partly of air, while the magnetic induction in the iron part of the circuit is far below saturation, and in such a circuit, theoretically as well as experimentally, the magnetic flux is always found very strictly proportional to the current, or in other words, the reactance is constant.

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Coming back now to the other proposition made by Dr. Pupin, to devise a "maid-of-all-work," a motor which does everything, I have such a machine in operation in our factory, and have used it quite extensively for experimental work for about a year and a half. It was originally built as an experimental induction motor, and after completing experiments with it, it is now used according to circumstances, either as a transformer or a frequencncy changer, or an induction motor to produce mechanical power, or as a generator to get currents of a frequency which I cannot get directly in another way, say 250 cycles per second, or to transform from three-phase to single-phase, or from single-phase to three-phase, etc. I shall be glad to show the apparatus to anyone of the gentlemen present, who visits Schenectady.

Dr. Pupin:—I observed of course s and s_1 and I know perfectly well what Mr. Steinmetz meant to convey by these quantities, but at the same time I do not agree with him that the geometrical factor is independent of the load, because there is a great deal of shifting of the magnetic circuits—what we call distortion. Now as to the second point, I am glad to hear that there is a machine of the kind described. I wish that we had one, so that I could show to students in one machine, the whole theory and practice of alternating currents: and I think that if that machine is not too expensive I should order one. If the General Electric Company really has that machine, I should then propose, in deference to that fact, that the title of the paper be "The Theory of the General Electric Alternating Current Transformer."

Prof. John E. Davies:—The remarkable feature of this paper, it seems to me, is its generalization, if I understand it correctly, of the notion of difference of phase and its changes. We have been so accustomed to regard difference of phase as more or less constant, and as included within the ordinary limits of 90 or of 180 degrees, that at first thought it seems to be somewhat difficult to enlarge our conceptions in this regard. That is to say, in the notion of slip, and in the use of the constant k to indicate it, it seems to me that Mr. Steinmetz has introduced here an exceedingly important idea, together with an appropriate notation for it. I do not know but that this idea of slip may be already perfectly familiar to the majority of electrical engineers here present, but it has not been familiar to me as an instructor in electricity and magnetism. I have been, of course, entirely familiar with the transformation of voltage and the transformation of current in the static transformer; but the transformation of periodicity and the use of a special constant in the formulæ to represent it, I must confess, struck me as a very novel, and at the same time as an extremely important modification of the usual treatment of the alternating current transformer. We can readily understand mere difference of phase when it amounts to one, two, or more periods, in advance or in retardation; but we have here an actual transformation of periodicity due to motion of the secondary, and

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it strikes me that that portion of the paper is an extremely original and valuable one both from a purely theoretical and practical standpoint.

Mr. Clarence E. Gifford, of Jamestown, N. Y., then read the following paper:

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25th, 1895. President Duncan in the Chair.

LOCATION OF GROUNDS IN ARMATURES, FIELDS, ETC.

BY CLARENCE E. GIFFORD.

This paper presents no novel scientific principles. The methods herein described are but simple adaptations of the principle of the Wheatstone bridge. They have been in use by the writer for several years, and he, having devised them for his own use, and found them very rapid, accurate and simple, is led to believe that they may be of considerable service to others. *The Electrical World* "digest" of March 16th notices a slightly similar, but evidently less perfect method, published by Mr. Bronsson in the London *Electrical Review*. The insufficiency of Mr. Bronsson's method in cases where two grounds, at some distance apart exist, is admitted. The methods herein described deal successfully with such cases.

If the work can be performed in a very quiet room, two or three cells of battery, a telephone receiver and connecting wires, comprise the necessary apparatus. In some cases two "table binding posts" and a foot or two of No. 18 or No. 20 bright iron wire will be a convenient addition. Where noise will not permit the use of a telephone, a dead-beat reflecting galvanometer, a milli-voltmeter, or some other form of delicate and rapid working visual indicator must be used instead. If an armature is to be tested without removing it from the machine; connection with the battery may be made through the brushes, first making certain that the short-circuiting switch is opened, if dealing with an arc machine. The points of connection with the battery need not be diametrically opposite, and may be made by the wires

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being firmly pressed against the commutator by an assistant, if more convenient.

Good electrical contact between metallic surfaces can better be secured by cleaning the same thoroughly with kerosene, which removes foreign matter, and is so fluid that it will in no way interfere with perfect contact, when moderate pressure is applied. Especially when making measurements of resistance of armature sections, it is even advisable to have the surface of the commutator quite wet with kerosene during the operation, as this avoids trouble from grease or dirt which might get on the surface from handling, subsequent to cleaning, and it also prevents the contact points becoming oxidized by any sparks which may occur at the moment of breaking contact. True, the oil is an insulator, but we use it in this case as a detergent simply.

Returning to the armature; connection being made between battery and commutator, first determine whether the armature circuit is complete throughout. If the circuit is complete, a click will be heard in the telephone when the two terminals of the same are brought in contact with any two contiguous bars of the commutator, or when contact is broken. If an open circuit exists on either side of the circuit, of course no sound will be heard in the telephone when used on that side, except when connection is made or broken by it between the bars lying on opposite sides of the break. See Fig. 1.

Close any open circuit temporarily by bridging between the two bars with a drop of solder. Two or more breaks can evidently be located by suitably shifting the battery contacts and searching as before. Open circuits will, of course, when an armature continues in work, soon cause burns between the bars that will indicate unmistakably their location. Having closed any open circuits, and the battery being connected to two points of the commutator, approximately opposite each other, one terminal of the telephone is connected to the armature shaft, or frame of the machine, and the other terminal is drawn completely around over the surface of the commutator, while the telephone is held to the ear. If only one ground exists, two balancing points, or points giving the least noise in the telephone will be found.

In an armature of ordinary construction, one of the points so found will be on the bar nearest the real ground, while the other balancing point bears what might be termed a "bridge relation"

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to the first, being at practically the same potential; the armature itself forming in reality a veritable Wheatstone bridge.

Now, shift the points of battery contact a few bars either way and the true ground, if but one exists, will be indicated in precisely the same position as before, while the other balancing point will shift every time the battery contacts are shifted. See Fig. 2.

If two grounds exist, two balancing points will be found, as before, but both points will shift more or less when the battery contacts are shifted, provided the grounds lie on opposite sides of the same battery contact. This case will be considered later.

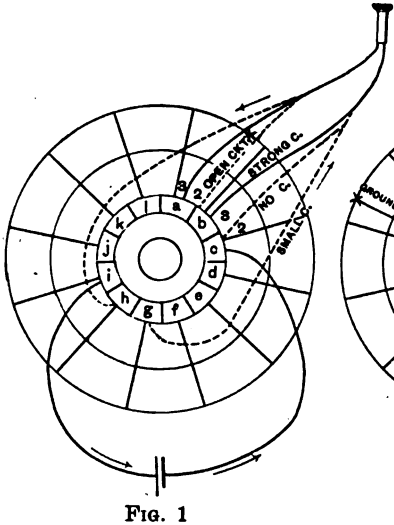

FIG. 1

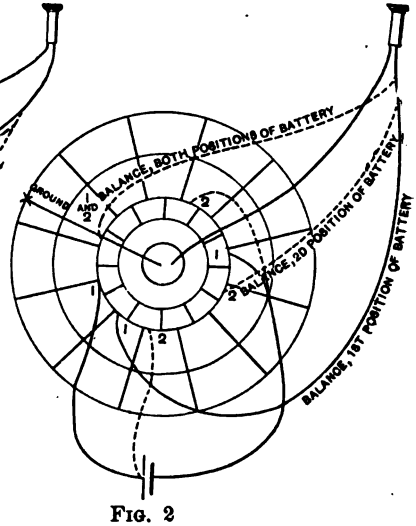

FIG. 2

In the case of one ground, having determined its location approximately, fix it as closely as may be by making and breaking contact with the telephone terminal on each of the more quiet bars, separately, until by comparison, the two giving the faintest clicks are determined. If your hearing has served you correctly these two bars lie nearest the trouble, the fainter one being the nearer. Prove the non-existence of a second ground by placing one of the battery contacts on the first bar to the right of the apparently permanent balancing point just found, and then on the first bar to the left of said point, the other contact being nearly diametrically opposite. This balancing point should still remain unchanged if no other ground exists.

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The next step is to connect the battery to these two bars just fixed upon as lying nearest the trouble. The armature still forms a "bridge," the portion included between the two contiguous bars to which the battery is now connected forming the one side, and the remainder of the armature, the other side. See Fig. 3.

One of the telephone terminals is now connected to the shaft as before, and the other terminal again drawn around the commutator. If the balancing point is found, say one-sixth to one-half, the long way around from one battery contact to the other, (these contacts being on two contiguous bars) the trouble lies in the coil between those two bars, and the point of trouble divides the coil in the same ratio as the balancing point divides the remainder of the armature, the ground and the balancing point being respectively nearest the same battery contact. If the balancing point falls on the same bar as one of the battery contacts, the ground is located on that bar or on the lead between it and the armature, provided the balancing point is found to be upon the same bar when the battery contacts are both shifted one bar to the right or left of their original position. See Fig. 4.

If the balancing point appears to be found within three or four bars from one of the contacts, the precaution should be taken to test its correctness by moving both battery contacts one bar toward the balancing point. If the trouble was between the battery contacts when in their previous position, this shifting of the contacts will now throw the balancing point clear around onto the contact which was, in the previous position farthest away from the balancing point. If, on the contrary, the balancing point remains unmoved by this shifting of the battery contacts, it shows that this balancing point is the point nearest the real ground, and that the ear was deceived in its first supposed approximation, which, with due care, however, is not likely to occur.

If such error has been made, the new point, as indicated, together with first the bar on one side of it, and then on the other, must be tried as points of battery contact; or, much better, make a new start with the contacts nearly at opposite sides of the commutator and proceed as before. A single 20,000 ohm ground on a one ohm armature should be located accurately in not over three minutes, in a quiet room. Higher resistance grounds require more battery and more care. Armatures of very low resistance also offer greater difficulty.

Where two grounds are found to exist, as indicated by the change of location of both balancing points, under the conditions

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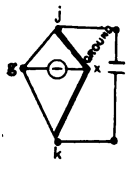
before stated, when the battery contacts are shifted, the following mode of procedure will answer the purpose well, and is simple. Fix the battery contacts at any two points of the commutator nearly opposite each other, preferably at points to be determined by trial, that will cause the balancing points to fall nearly diametrically opposite to each other, and determine and mark the two balancing points, as then shown. Now place the battery contacts on the balancing points just found. If only one ground exists, the two balancing points and one battery contact will all be coincident in one point. If two grounds exist, both balancing points will be shifted from their former position. Open the arm-



[Analogue to Fig. 3.]

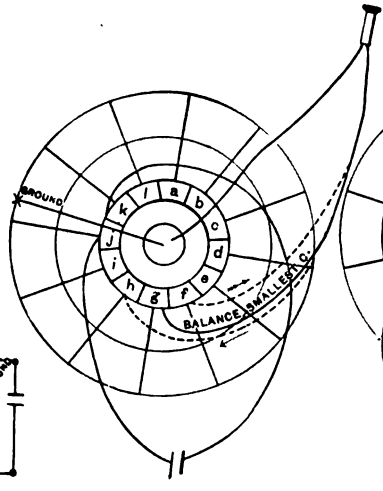


FIG. 3.

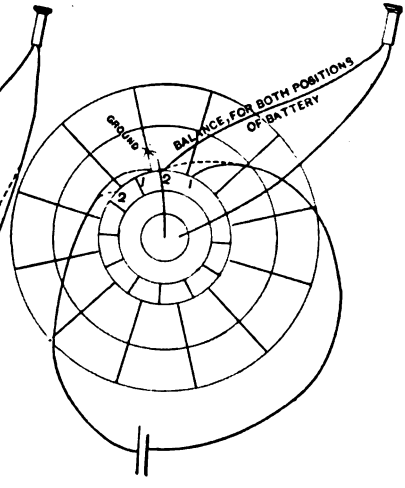


FIG. 4.

ature circuit by unsoldering one of the ends of a coil connecting with the lead of the bar that is marked in the first part of this test, as one of the balancing points. Place one of the battery contacts on the armature shaft, and the other on the marked balancing point that is farthest from the point where the circuit has been opened. Next place one telephone terminal on the first bar to the right of the opened wire, and draw the other terminal from the same point, toward the right, over the surface of the commutator. The telephone will be absolutely silent until the moving terminal has just passed the ground nearest to it, and strikes the first bar beyond the same, when it will click. This

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ground lies in the coil between this first bar giving a click and the one passed just previously, or else in the said previous bar.

The other ground is obviously to be located in a similar manner, by placing one telephone terminal on the bar just to the left of the open wire, and from that point searching toward the left with the other terminal. Only in cases where one ground is of very low, and one of very high resistance will any difficulty be experienced in locating both accurately before either is removed.

The coils thus indicated may have their terminals unsoldered, when it can be readily ascertained with each, whether the ground be in the coil or in the bar just preceding it.

If scientifically inclined, or if otherwise preferable, the circuit may be opened at a point somewhere midway between the two indicated coils instead of disconnecting those coils, and the exact location of each ground determined as follows: Take a piece of "broom wire" about 18 inches long, new and clean, screw the ends firmly into two clean, brass table binding posts, and into the other holes of the same posts, screw the battery terminals. Have an assistant press the corners of the bases of the binding posts into very firm contact with the two bars that lie at the ends of the indicated coil, observing the directions previously given for securing clean contact. Place one telephone terminal in contact with the shaft, and with the other find the balancing point on the wire. This point will indicate the relative position of the ground in the coil, or commutator bar, as the case may be. If more than two grounds were suspected, the two lying the farthest apart would be approximately located by the first part of the two-ground process, and if these coils were not disconnected before proceeding farther, it would be well to make two openings in the circuit, close to and lying between these outer grounds, then locate definitely these two extreme grounds, and proceed with the remaining section somewhat as with a complete armature, except that you would commence by connecting the battery to the terminals of this section, and would then bridge the telephone from the shaft to the different portions of the section, and would complete the process by applying the remainder of the two-ground test.

In dealing with a cross-connected Gramme ring, an obvious change would be made in the points of application of the battery; and as many points of apparent trouble would be indicated as there were series of cross-connections.

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After location of these points it would be necessary to use the auxiliary wire loop, as before described, between these points, to determine which is nearest the trouble. This fact being determined, it would in case of a single ground (indicated by the permanency of the balancing point) become necessary to remove the cross-connections from two bars before proceeding farther. The auxiliary wire loop would properly be used to complete the process.

The ordinary "closed coil" ring or drum armatures are types to which these methods are directly applicable.

The sections of open coil armatures would receive the same treatment as field coils.

Familiarity with any special forms of armature will doubtless suggest to the ingenious mind, modifications of these methods suited to those forms, but it would be improper to attempt here to deal with specialties whose names are legion.

Where wet grounds exist it will always be better, when practicable, to dry them out before making the final test, as certain sections may show faults which will not be permanent. Wet grounds will of course give a click in the telephone when bridged from the commutator to the shaft when no battery is attached, owing to galvanic action of the water on the copper winding and the iron core.

Whenever necessary to deal with wet grounds in testing, it is better to make at least four tests, reversing the battery after each test, and taking the mean of the four determinations.

Field coils, also any wires of uniform cross-section, the extremities of which are accessible and within a reasonable distance of each other, can of course be easily tested for grounds by soldering or firmly clamping a bare wire of suitable size between the extremities of the conductor to be tested, applying a battery to the junctions, and bridging with a telephone between the bare wire and the object upon which the conductor is grounded. This will give only the location of a single ground, or the "resultant" of two grounds. A "T.-H." rheostat should have the battery connected to the two extremities, and the point of apparent ground determined by bridging with a telephone between the frame and the several contact plates. Then apply the battery to the frame and point of apparent ground, connect one terminal of the telephone with each extremity successively, and search from it toward the center

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with the other terminal, as in the case of searching for two grounds in an armature.

In determining the location of grounds that are of very low resistance, a good induction coil similiar to that used in the Blake transmitter may be used with advantage in connection with the telephone receiver. The receiver is placed in circuit with the secondary of the coil, and the "bridging" is done with the primary. With high resistance grounds the best results are obtained by using the receiver only.

After the reading of Mr. Gifford's paper, a recess was taken until 8 P. M.

The afternoon was devoted to an inspection of the power house of the Niagara Falls Power Company, the electric plants of the Pittsburg Reduction Company, and of the Niagara Falls and Buffalo Electric Light and Power Company, and the mill of the Niagara Falls Paper Company.

The evening session was called to order at 8.20 P. M. by Vice-President Wm. A. Anthony, when the following inaugural address was delivered by President Louis Duncan:

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Inaugural address of the President before the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1895. Vice-President Anthony in the Chair.

THE SUBSTITUTION OF ELECTRICITY FOR STEAM IN RAILWAY PRACTICE.

BY LOUIS DUNCAN.

In an address delivered before this Institute in June, 1892, Mr. Frank J. Sprague spoke of the coming development of electricity as applied to railways, and outlined his views as to the direction of this development. In the last three years great extensions have been made in electrical transportation, and it seems well to review briefly the amount of these extensions and their direction. In this paper I shall consider electric traction as it stands at present and not the possibilities of the future.

In the last seven years electricity has largely taken the place of horses for tramway work, and it is now beginning to replace cables, although the latter have been recently installed at great expense. At first the lines were confined to the limits of towns and cities, but they have been extended first into the suburbs, and then to neighboring towns, and the extensions have brought them in competition with the steam roads. The reports of the earnings of the railroad companies in the United States show that after paying fixed charges only a small amount of the net profit remains to be applied to dividends on the stock. Any general decrease in the earnings, even if it is only a small percentage of the total amount, will wipe out the narrow margin that is now applied to dividends, and the absorption by the electrical lines of the local travel formerly conducted by the steam lines promises to do this. At first the managers of the larger steam roads ignored the growth of their electrical rivals, but the time has come when they can no longer ignore the decrease in the

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receipts from their local passenger travel, and they are beginning to face the difficulty and to carefully study the situation.

In this paper I will briefly take up the following questions:

1. Given a railroad system at present operated by steam; will it pay to change entirely to electricity, or to make a partial substitution, and how should the change be made?

2. If entirely new lines are to be built, is it likely that it will pay to equip them electrically, and how should they be equipped?

3. I will describe the equipment of the Baltimore and Ohio tunnel plant and draw from it what morals I can.

In order that it should pay a railroad to make a change in its motive power, the effect of the change must be either to increase the receipts or decrease the expenses by an amount equal to the interest on the first cost of the change. That is, there should theoretically be such a gain; practically, the amount should be greater in order to justify the change, to take into account those elements not capable of exact calculation, and also the fact that an increase in the fixed charges of a road is a more serious matter than the mere amount of it, for although the average for a number of years might show a gain by the substitution of electricity in a bad year the increased fixed charge might cause difficulty.

There are two very distinct sides to the question of transportation, the passenger side and the freight side, and their requirements for good service are very different.

First, taking up the question of passenger travel. The receipts of a road are increased by running trains at short intervals and at high speeds, and this is a condition peculiarly favorable to electricity. On an electric line, short trains equally distributed over the track give a greater station efficiency, and the lowest cost of equipment of both station and line. The cost of train service is somewhat greater, but is compensated by the saving in the other items.

The cost of hauling a given number of passengers between given points by steam is greatly increased when the number of trains is increased. The efficiency is less, and the cost of equipment and of train service is greater. Wellington states that doubling the number of engines for a given traffic increases the cost of transportation about 50 per cent.

On the other hand, if we take up the question of freight traffic, the conditions of greatest economy are reached when trains of a maximum weight are hauled by a single locomotive. The

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tendency in late years has been in the direction of increasing the size of the locomotive, the capacity of the cars and the length of the trains. These changes have necessitated more solid and expensive road beds, heavier rails and general strengthening of bridges. The outlay has been enormous, but the decreased cost per ton mile for freight transportation has shown the wisdom of the change. On one of the larger roads which publishes careful yearly statistics, I find that the cost of transportation per ton mile in 1870 was 1.15 cent, and in 1890 .56 cent; on another road it was 1.9 cent in 1864 and .447 cent in 1893. The number of tons per train mile on the first road in 1870 was 103, while in 1890 it was 226. In attempting to carry on traffic of this kind by electrical locomotives operated from a central station, we find that we are at a great disadvantage because of the irregular service necessitated by the freight traffic and the unequal distribution of the load along the line. Suppose, for instance, that there were two stations supplying the line and that the traffic was uniformly distributed along it, then the capacity of each station would be one-half of the total required capacity. Suppose, however, that the entire traffic was concentrated in one train, then each station would have to have a capacity equal to the total power required for hauling the entire traffic, as the train would be first supplied from one station, and then from the other. The line also would have to have a capacity suitable for handling the total traffic. If a number of heavy trains were used, and the traffic was irregular and liable to be congested at one point, as in the case of freight service, then again the capacity of the stations would have to be greater than that required to supply one-half of the normal traffic. If we were to decide to transmit the current to a longer distance and to supply all the track from one station, using transformer devices along the line, then the capacity of the station itself would only be that required for the normal traffic of the line, but the transformer devices would have to be sufficient to handle the maximum traffic of the section which they supplied, and would have to be given a capacity greatly in excess of their average load in order to supply this energy. We must distinctly bear in mind in considering the application of electricity to steam roads, that any departure from a uniform distribution of load along the line will increase both the cost of equipment and the cost of operation.

In looking over the reports of the same road from which I

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have given freight statistics, I find that in 1870 the receipts per passenger mile were 2.09 cents, while the expenses were 1.59 cents. In 1890 the receipts were 1.9 cent, while the expenses were 1.47 cent. During this period the passengers per train mile have decreased from 79 to 59. Comparing these figures with those given for freight transportation, we find that the two types of traffic have gone in opposite directions in the period we have been considering. The amount of freight transported per train mile has more than doubled, and the expense has decreased more than one-half. The passengers per train mile, on the other hand, have decreased, and the expenses have changed only a slight amount, notwithstanding the greater economies that have been put in force in the interval. Passenger traffic has come in the direction in which electricity is the most economical for transportation; freight traffic, on the other hand, has gone in the direction where electricity becomes most costly. It might be argued that some new scheme for freight transportation by electricity might be used, but it would be difficult to devise any system more economical than that at present in use, and the great amount of through traffic on freight lines precludes the possibility of devising any system which differs radically from that at present in use. For instance, taking the figures from the records of the Pennsylvania Railroad for 1893, I find that the freight mileage of foreign cars on the lines of the Pennsylvania road east of Pittsburg is in round numbers, 370,000,000, while the freight mileage of home cars is 436,000,000, making almost 46 per cent. of the total mileage made by foreign cars. It would seem, then, impossible to change the present system of freight traffic without disorganizing the service and decreasing the freight revenue of the road. The importance of freight traffic is shown by the fact that the earnings from freight on all the roads in the United States is between two and one-half and three times as great as that for passenger traffic. The New York Central Railroad Company in 1892 received from their freight traffic $26,000,000, and from their passenger traffic $13,000,000. On the lines of the Pennsylvania Railroad east of Pittsburg the freight receipts were $47,000,000 as against $17,000,000 for passenger receipts.

Suppose, then, the question comes up before the managers of a road as to whether they are to equip their lines to be operated entirely by electricity. It seems to me as matters now stand it

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will not pay trunk lines to change the method of operation for freight traffic, and the question to be considered would be the operating of the lines partly by steam and partly by electricity. Let us consider if it is possible to run the passenger service wholly or partly by electricity. Considering a two track road doing a through as well as a local business, I think we can decide that, unless the case be an exceptional one, it will not pay to equip the main line electrically. It is necessary that the through express service be continued and that the freight service be continued, and an attempt to operate the local trains with the through trains could not be successful if there was any considerable amount of through traffic. With a four-track road the condition of affairs is somewhat different. If the road operates between cities acting as terminal points for all passenger traffic, as with some of the lines between Boston and New York, then by equipping all four tracks it would be possible to run express service at short intervals on two of the tracks, and on the other two tracks to run freight and local trains. At present it would not pay to use electric locomotives operated from a central station for the freight service, but the local service could be operated electrically; and as the speed of the local trains would be approximately equal to that of the freight, there need be no serious interference with the traffic. We would then have express passenger service working under favorable conditions—that is, with a number of trains evenly distributed, a local service operated under similar favorable conditions and with no interruption to the freight traffic. If the road, however, is to transport a considerable number of foreign cars as, for example, the New York Central or the Pennsylvania railroad, then the condition of affairs for express service would not be so favorable, and the question of the equipment of the tracks for express service would have to be carefully considered. As far as the branch lines go, whether it would pay to partially or wholly substitute electricity for steam depends upon the local conditions. A long branch with a small amount of local traffic it would not pay to equip, but on a short branch with considerable passenger traffic and comparatively little freight traffic such equipment would pay. I find that in 1892 the total number of through passengers carried by the New York Central road was 234,650, while the number of local passengers was 21,978,979. It will be seen that the through traffic is but a small percentage of the total number of passengers,

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and that the question of preserving the local traffic is of great importance. Now the greater part of this local traffic will, in the next few years, be taken by the electric roads paralleling the steam road, unless some effort is made either to control the electric roads or to give an equally good service between adjacent towns. This latter is possible, using the ordinary steam tracks, only when the distances between towns are small, and the amount of freight or through traffic is also small.

There are certain kinds of local traffic which the steam roads must, to a large extent, lose, and which in the nature of things they cannot regain. In large cities having a considerable suburban traffic the trolley roads, forming as they do a network of lines within the city and extending in every direction into the suburbs, offer advantages with which the steam roads cannot compete. In Philadelphia one of the large steam lines lost so much traffic that it has attempted to regain it by reducing prices and increasing the number of trains. In this effort it has partly succeeded, but at the cost of greater expense and decreased receipts. To counterbalance this loss at central points railroads may hope, by the introduction of electricity, to increase their earnings along the lines and on their branches.

As to the nature of the equipment that will be required, it would depend on the work to be done and the branch that is to be equipped. In some cases it might be well to use single electric cars running on the steam tracks between towns, and on the local tram lines in the towns. As the speed would be very different in the town and on the railroad line, and as the voltage could also be different, it would be well in this case to use a number of motors on the car, and to use a series parallel controller, the motors being in series for the town traffic. For instance, suppose we wish to run at a maximum speed of 40 miles per hour between two towns, and it is economical to use 1,000 volts on the line, we could use two motors on the car, run them in parallel on the main line at a speed of 40 miles per hour, while in town, with a voltage of 500. we could run them in series at a speed of 10 miles per hour. I can hardly imagine a case where the three-wire system could be economically used for such service on the steam lines.

The condition of affairs in electric transportation is at present curious. The trolley companies, by extending their lines, are working from tramway transportation to through transportation.

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They are attacking the problem by development from small motors to larger ones. The railroad companies starting with the large units are coming down in the direction of the present trolley systems, as in the case of the Nantasket Beach road of the New York, New Haven & Hartford company. Perhaps in the future they will meet, and some standard electrical system will be adopted for the present steam road. I think then, that in the case taken up, the policy of the road will be to equip those branches for which the conditions are favorable, with a trolley, run comparatively large motor cars capable of drawing one or two ordinary passenger or freight cars as trailers, using the present steam service for their freight traffic when necessary. This will allow the necessary through travel, will give the required local service between towns, and will not interfere with the freight traffic.

As for the systems to be used for such services, I believe that at the present moment the continuous current overhead trolley system is the only one that can be selected with a certainty of successful operation. It gives a minimum complication in the way of conveying the current to the cars, it allows a considerable range of speed with a comparatively high efficiency, and our experience with it is such that successful operation could be at once guaranteed. By using different voltages in the towns and on the line, both high and low speeds can be obtained. If the line to be operated is to be very long, it might be best to use rotary transformers at different sub-stations along it, the line being supplied by continuous currents from the sub-stations. In fact, the three systems that are at present possible are: First, the ordinary direct current system; second, a system in which direct currents are used on the line and rotary transformers supplied by alternating currents are placed along it, and third, a two or three-phase system supplying rotary field motors on the cars. In the latter case it would be well to employ different periods in the towns and on the lines.

The second case which I wish to consider, is that of roads built for an entirely new electrical equipment such, for instance, as the elevated roads in Chicago and the underground rapid transit road in New York, or the proposed Washington-Baltimore Boulevard line. In most of these cases the traffic is almost entirely a passenger traffic, and the conditions are especially favorable for the operation of electricity. Taking, first, the case of

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the New York underground road, there will probably be required about 150 trains for local service, each train having five ordinary cars and a motor car. For the express service there would be about 25 trains of, say, four ordinary cars with a motor car. For this it would probably be best to use the direct current three-wire system, one of the cars on the train being equipped with motors and acting as a locomotive. With four motors on a car, the system would be efficient at all practical speeds, and if desired, a large part of the energy could be thrown back on the line when the cars are being stopped. In the case of the local trains, a simple calculation will show that a very small part of the total energy expended, is used in overcoming the track resistance, while a very considerable part is employed in accelerating the train and afterward wasted by braking. I have calculated the amount of energy which can be practically saved under the conditions of local and express traffic on the New York underground road, and find that with motors of ordinary efficiency about 45 per cent. can be returned. If storage batteries are used in connection with the central stations, the batteries being located along the line, a uniform load can be thrown on the stations, and their capacity may be reduced to almost one-half, as compared with a system in which the energy is not returned, thus greatly decreasing both the expense of installation and of operation. As it is possible at present to obtain batteries with a rapid discharge rate at very reasonable prices and with a guarantee for repairs, that place them well within the limit of commercial calculations, a system of this kind offers some advantages over any other system that could be applied to the operation of the underground road. An alternating current would hardly be economical for this work, as it precludes the possibility of returning the energy to the line, and as the variable speed required makes it uneconomical as compared with the direct current system using, say, four motors with series parallel control. In the case above cited, shunt motors would be used, and it would be possible to get a contact with the line that could not under any circumstances be broken. The case of the elevated roads is very similar to the one I have cited, except that in existing structures shorter trains would be used, and the cost of equipment for a given number of cars would be somewhat greater.

Baltimore has been the pioneer in almost every branch of transportation. In ocean service, the record of the Baltimore

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clipper is a tradition of our maritime supremacy. The Baltimore & Ohio railroad was the pioneer steam road. An electric road from Baltimore to Hampden, built in 1885, gives us a right to boast of our pioneer work in electrical tramways. The immense locomotive for the Baltimore Belt Line tunnel is the first instance of the direct displacement of steam by electricity, and the line over which it is to be operated is the first through steam line to be equipped electrically. The Baltimore & Columbia Railway Company owns in Washington the Eckington and Soldiers' Home Railroad and the Belt Line railroads and has franchises for extensive additions to their present mileage. In Baltimore they are constructing a road in the city and beyond it to Ellicott City, and they have also purchased a steam line running from Baltimore to Catonsville. They have rights of way from the terminus of their Baltimore lines to the lines they own, and are preparing to build in the District of Columbia. The problem offered is not a simple one, but it is one of the most attractive that can be presented to electrical engineers. Speeds of 60 miles per hour are to be used for the cars outside of the city limits, and within the city limits ordinary speed is to be employed. In the District of Columbia, overhead trolley lines are not allowed and some type of conduit will have to be employed. In fact, there is presented almost every problem which must be solved, if electricity is to displace steam in the future with the same rapidity that it has done in the past. Many high-speed electric roads have been projected, a number of them occupying considerable space in the newspapers, but I think this road will be the first to solve the detailed problem of interurban rapid transit.

The last subject which I wish to take up is the electric plant for the Belt Line tunnel of the B. & O. railroad. In this case there is no question of economy in the employment of the electrical locomotives, as the plant adds considerably to the cost of operating the road. The Belt Line tunnel runs beneath the city of Baltimore for a distance of one and one-quarter miles, then to the outskirts of town through open cuts and short tunnels. There is a grade of .8 of one per cent over almost the entire length of the tunnel proper, while one-half mile beyond it there is a grade of one and one-half per cent. Being in the middle of town it would have been difficult to have provided a satisfactory ventilating plant, even supposing that ventilating

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plants had been successful in other localities, which is not the case. The managers of the B. & O. Railroad Company wished to provide a satisfactory service, and considered a number of plans for drawing their trains through the tunnel without the annoyance due to smoke and gases. After careful consideration, they concluded that electricity was the most satisfactory means to accomplish this, and the General Electric Company was confident enough of its ability to successfully equip the road to make a contract with the B. & O. company to haul its trains over the Belt Line, the contract being dependent upon the successful operation of the plant. The total length of the line equipped is about three miles, the extension beyond the tunnel being for the purpose of assisting the freight locomotives to haul their trains up the one and one-half per cent grade on the line beyond the tunnel. There are to be three locomotives, and it is calculated that the traffic can ordinarily be handled by two of them. The steam engines are not to be taken off the train, but hauled through the tunnel by the electric locomotive which switches off at the terminus of the line. To operate these machines, a station has been erected which contains 3,000 horse-power of electric generators, and an overhead line has been equipped to transmit the current to the locomotives. With respect to the station itself, there is little that is novel. There are four 750-horse power Allis-Corliss engines directly coupled to generators of the same capacity, the generators having a voltage of 600 at no load, and 700 at full load. The foundations have been partly erected for a fifth unit in case it is found necessary. The building also contains a lighting plant having a capacity for 400 arc lights, and four thousand 16-candle-power incandescent lights. Provision has also been made for an extension to this lighting plant when the stations for the Belt Line are erected. There are two incandescent machines, and one of them will be used to supply the one thousand 32-candle power lamps which have been installed in the tunnel. Perhaps the most novel feature of the plant is the overhead structure that is employed. The conditions to be met were peculiarly difficult, and the ordinary under-running trolley was considered impracticable. The tunnel is very low in places, and the management of the road decided that the conductors could not be placed over the cars, but should be placed in the middle of the tunnel between the tracks. Outside of the tunnel the conductor is still between

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the tracks, but is elevated to a height of 22 feet, while inside of the tunnel it is only 17 feet from the top of the rail. The conductor consists of an iron trough made of two Z bars riveted to a cover plate 12 inches wide, leaving a slot one inch wide between the Z bars. In the tunnel this trough is supported from transverse channel bars secured to expansion bolts which are fastened in the top of the tunnel. There is a double insulation, one porcelain insulator being between the trough and the channel bars, and another between the channel bars and the expansion bolts. Outside the tunnel the trough is supported as follows: At distances of 150 feet, light iron columns with cross trusses are erected, and between these trusses are hung catenaries supplied with a number of suspension bolts. Transverse channels similar to those used in the tunnel are fastened to these bolts, and the trough is fastened to the channels. The Z bars are made in lengths of 30 feet, the opposite bars breaking joints with one another, the lengths being riveted together and then bonded with "Chicago" rail bonds. Suspended on the same transverse beams as the trough, are three copper cables of 1,000,000 circular mils area, which serve as feed wires, and which are connected at intervals with the trough, there being, of course, one trough for each track. For the return circuits the tracks are bonded as in ordinary railroad work, there being cross bonds and at intervals connections with a copper cable of 1,000,000 circular mils area carried in a wooden trough between the tracks. The contact arrangement that is to be used consists of a brass shoe traveling in the trough, and connected with the locomotive by a flexible saw-buck arrangement which has a very considerable range in every direction. The current is transmitted to the motors by a copper cable, and in case of the shoe sticking in the trough, a safety pin is arranged to break with any desired strain. Where switches are used, there is a tongue worked by the lever which operates the track switch, and which serves to direct the shoe. This structure, although exceedingly massive and expensive, promises to give an excellent contact at all times, and it requires no care from the motorman.

The locomotives are the most massive in the history of either steam or electrical transportation, and the weight, which amounts to 95 tons, is on eight driving wheels, so that the full tractive power of the locomotive will be developed. On each axle there is sleeved a 6-pole motor, there being considerably play between

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the axle and the sleeve, which latter is spring-supported from the frame. In this way any heavy blow due to irregularities in the track is taken through the springs, and the wear both of the track and locomotive is reduced. On the armature shaft are projecting arms which move between lugs cast on the wheels, thus allowing the necessary relative motion between the axle and armature.

The situation in the Baltimore Belt Line plant is this: The station is completed, and is being operated daily. One of the locomotives is on the ground set up and ready to run, and the overhead work is finished with the exception of a short length which was interfered with by a temporary bridge over a cut. The latter has been removed, and the plant should be ready to run this week.

If this equipment proves successful, it will open a limited but important field for the introduction of large electric locomotives. There are in the United States a number of tunnels whose operation is anything but satisfactory at present, which can be equipped as the Baltimore tunnel is. Not only would the economy of the station be increased, but the substitution of electric for steam switching engines would result in a very considerable saving.

This is the last of the subjects that I proposed to consider. In this paper I have not indulged in prophecy, nor have I imagined any apparatus or equipment which cannot be bought to-day in the open market. But to me it seems that the present is a crisis in the history of railroading. Up to the present the steam roads have ignored the competition of electric roads, or they have fought them. To-day they cannot afford to do either. In a few years electric roads will have absorbed practically all of the local traffic and will begin to cut into through transportation. The steam roads cannot afford this, and their only safety is to make of electricity an ally instead of an enemy, and this before it is too late.

The conclusions that I finally reach are:

1. The tendency of passenger transportation on the steam lines has been in the direction of the greatest electrical economy, while the tendency of the freight transportation has been in the direction of the least electrical economy.

2. It will not pay any through line with considerable traffic, having two tracks, to equip their main tracks electrically.

3. With four-track roads it will pay to equip all of the tracks

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electrically unless a considerable portion of the business is through passenger traffic.

4. It will pay all the larger roads either to equip a number of their branch lines electrically, or to control competing electric lines.

5. In order to remain on a dividend paying basis, it is imperative that most of the two-track lines either build additional tracks, or control the electric railroads that parallel them.

6. Believing that ultimately all of the traffic will be done by electricity, it is imperative that the managers of steam roads keep in touch with electrical progress.

Discussion.

Vice-President Anthony:—I think it has not been customary to discuss an inaugural address, but the nature of this one is such, that doubtless some would like to comment upon it, and I understand that Dr. Duncan wishes you to express your minds freely. The paper is open for discussion.

Mr. Steinmetz:—While I shall not be able to discuss, and still less to criticise this paper, I desire to add a few remarks in connection with one point that has been brought out by Dr. Duncan, namely, the different methods of operating electric railway motors.

There are mentioned:

1st. The continuous current system.

2nd. The continuous current motor operated from an alternating main line by means of rotary converters.

3rd. The alternating current motor.

I think it may be of some interest to investigate the limits of application of these different systems, and find out in which case the one, and in which case the other is preferable.

All electric roads, as far as they are in operation to-day, or as we expect to see them introduced in the near future, belong under the following classes:

1st. *Surface roads in the interior of cities.*—On these roads the continuous current railway motor with overhead trolley and ground return, operating at a potential of 500 to 600 volts, is used practically without any exception. Only very few roads use either an underground conduit or a double trolley. On city surface roads there is at present no hope of seeing the continuous current motor replaced by any other method of electric propulsion, since the continuous current motor has proved itself entirely satisfactory under the conditions of such a road, and the distances are such that they can easily be reached by 550 volts, or a three-wire system with 1,100 volts between the outside wires. The double

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trolley required with alternating current motors, practically excludes them from such roads with many switches and cross-overs.

Only in underground conduit roads can the alternating current motor be expected to find an application on city surface roads. The double trolley in this case is no objection, since conduit roads operate usually with double trolley, and the alternating current system offers in this case the advantage of permitting very low voltage at the trolley lines, due to the possibility of feeding by stationary transformers. Thus we may expect to see the alternating current motor introduced on conduit roads.

2nd. *The second application of the electric motor is to elevated roads.*—Here the continuous current series motor is just being introduced, and, as far as I can see, I do not believe that there is any hope at present of replacing it with the alternating motor, due to the particular nature of the elevated road service, where trains never run at full speed. Take as an instance the Manhattan elevated road in New York. Excluding express trains, I do not believe that on this road a train ever runs at full speed, because before it has reached that point it has already approached so near to the next station that it has to slow down. Now you see very readily that the alternating current motor, while it can operate at its proper speed with very high efficiency, and can get any starting torque desired, nevertheless does not give this flexibility of speed, but while accelerating, has to run on the rheostat, and thus does not give the same efficiency as the continuous current motor under the same condition. For this reason the alternating current motor is less suited for elevated roads, the more so, since the main advantage of the alternating current system, the opportunity of feeding by means of stationary transformers, is of no essential value for elevated roads which are of moderate length, and have a very heavy traffic; and where it is thus possible, with a comparatively small investment, to feed the road by continuous current at 500 to 700 volts, or even more, from one or a few power stations. Thus, these two fields of application will be held by the continuous current motor for a long time to come.

3rd. Another field in which the electric railway motor is rapidly gaining is in the *suburban and interurban traffic*, or those lines which extend from the city roads far out in the country, or connect adjacent cities, as for instance the net work of railways stretching out from New York City along the Hudson and East Rivers, or from Boston out to Lynn, Salem, Dorchester, etc.

If the length of these roads becomes considerable, it becomes impossible to feed by continuous currents from one central station, and thus some other method becomes necessary. Either you have to put frequent power stations along the road, which is to say the least, awkward and inconvenient, or you have to use alternating current, and in the latter case two possibilities exist: either continuous current motors on the cars, supplied by rotary converters from alternating main lines, or alternating motors on

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the cars supplied by stationary transformers. Both of these methods offer advantages and disadvantages.

The *system of rotary converters* has the advantage of allowing the use of a standard continuous current railway motor which is able to run over the city lines also, so that the same cars and motors can be used on city surface roads and suburban and interurban roads, the rotary converter merely taking the place of a supplementary central station. However, in general the speed at which the suburban roads are operated will be higher than the speed of city roads, and thus for this reason special motors, that is. special cars will be required. Furthermore, the use of a commutator makes it desirable not to exceed 500 to 600 volts at the motor. This voltage means a frequent use of rotary converters along the road, which is objectionable, since the rotary converter as revolving machinery, requires some attention and supervision, that is, in reality constitutes a substation.

The *alternating current motor* has the disadvantage of requiring a double trolley. This may not be very objectionable on suburban roads with few switches and crossings. It has, however, the essential advantage of running at a fairly constant speed, independent of the load, and will not race when running down hill, but will in this case return the power as generator into the line; nor will it slow down when climbing hills. This is quite a valuable feature in single track roads, where at present with the continuous current motor the car going down hill has usually to wait on the switch for the car going up hill. Furthermore, the alternating current motor is more reliable in its operation, and since the alternating main current enters the motor field only, which is stationary, a higher voltage is permissible, that is a greater distance between the supply transformers. The main advantage, however, is the possibility of feeding the line by stationary transformers, which need no supervision, but are to be considered merely as a part of the feeders. Thus, on these roads, wherever it is not absolutely essential to run the same cars over continuous current city roads, the use of alternating current railway motors on the car, supplied from an alternating current trolley line, will be preferable to the system of rotary converters.

4th. A further field for electric railroading is to be found in *high-speed, long-distance roads* for mostly passenger traffic, connecting important cities. Thus far nothing has been done in this line, although considerable discussion has taken place. I am sure that the future will bring such roads. It is obvious that in this case only alternating current motors are applicable, mounted directly on the axles and fed from high potential mains by transformers. The speed of these roads must be very high, since steam locomotives have already reached a speed of about 100 miles an hour, and there would be no demand for the electric motor if it did not offer an essential advantage over the steam locomotive, and such advantage can only be found in the possibility of using very high

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speeds, due to the absence of reciprocating motion. Thus speeds of 150 miles per hour maximum, with an average speed of 100 to 120 miles per hour, will be just as safe as the present steam locomotive speeds.

The objection has frequently been raised against the alternating current motor for railway service, that it does not give sufficient starting torque. This objection holds no longer, for the starting torque of alternating induction motors, for instance of the three-phase type, far exceeds that of the continuous current motor. Theoretically this is easy to understand. The torque of a motor—starting torque as well as running torque—is proportional to the product

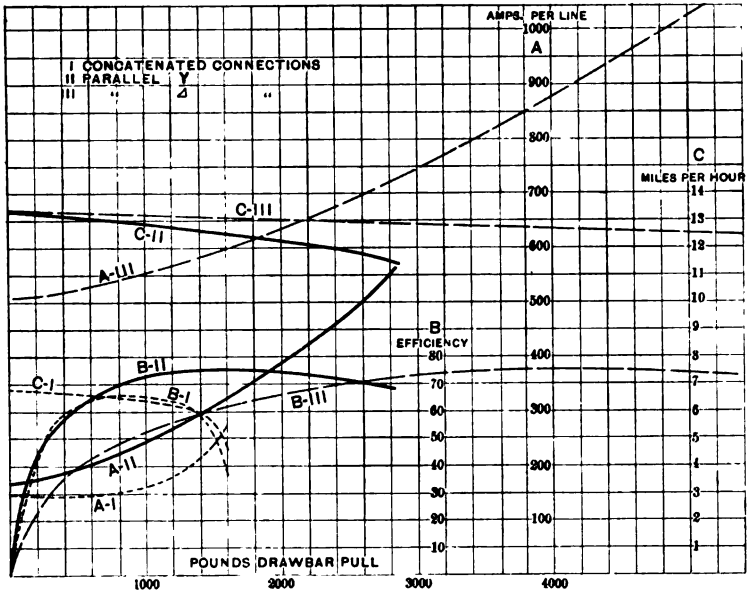

FIG. 1.—G. E. I. Three-phase Railway Motor, Drawbar pull with 33" Wheels and Two Motors per Car.

of armature current into field magnetism. In the continuous current motor at normal running, the field must be fairly near saturation. Thus an increase of field magnetism is possible to a limited extent only, and an increased torque, therefore, requires a nearly proportional increase of current. In the alternating current motor, however, the field is very far from saturation at normal running, and thus can in emergencies—as when starting on a curve or when climbing heavy grades—be doubled and tripled. Therefore, to get four times the torque in the alternating current motor, by means of doubling the field strength, only twice the current will be required, while the continuous current motor probably requires three or more times the current.

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Furthermore, the production of heat in the alternating current motor is distributed over the whole apparatus, and thus a much greater heat can be taken care of for a limited time.

I have here the testing record of a car equipment with two three-phase induction motors (Fig. 1). They are designed to operate with the same speed and are of about the same size and weight as the standard General Electric Company's continuous current railway motors, G. E. 800. They are controlled by a method which I have devised, and whereby it is possible to operate them at full efficiency and half speed as well as full speed, thereby offering the same advantages as the series parallel control of the continuous current railway motor. The curves A denote current per line required by this motor when operating at its rated voltage of 110 volts between the lines. The curves B give the efficiency including bearing and gear friction. The curve C gives the speed, all as function of the drawbar pull, or pull at the periphery of a standard 33 inches wheel. The normal rating of these motors is 800 lbs. drawbar pull per motor, or 1,600 lbs. per car. As you see, in concatenated control, at half speed, the drawbar pull rises to 1,600 lbs., and at full speed to over 2,800 lbs., while by means of an emergency switch which changes the field intensity of the motor, the maximum drawbar pull can be increased to over 8,000 lbs., that is far beyond the heating limit of the motor and far beyond the pull which will slip the wheels. That means in other words, that the alternating current motor can give any starting torque which possibly can be required, just as well as the continuous current series motor.

MR. OBERLIN SMITH :—I think most of us will agree with Dr. Duncan's conclusions in regard to the electrical equipment of passenger lines, but I do not see that we need rule out freight trains entirely, because we have a road equipped with trolley lines especially for passenger cars. We probably shall continue to run steam locomotives for the freight trains at first, but it seems to me that we shall learn ere long, and without any great change in the general system of freight traffic, how to electrically run freight cars too. It must be remembered that the long freight trains we now have are an *effect*, to some extent, of the steam locomotive system. Just as soon as the locomotive is gone for passenger work, new schemes will doubtless be devised. There would seem to be no inherent reason why we cannot run freight cars, one, two or three together, dividing up these long trains, which in many respects are a nuisance to railroad men and a source of danger and trouble, especially where they have to be divided for transfer at branch roads, and to leave a few cars at way stations, and all that. It seems to me very likely that when we once learn how to get passenger cars rapidly and cheaply over the roads, that freight cars also will gradually be run in the same way. So I do not think we should assume that we shall have to perpetually keep the steam roads running for freight, although

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it may be that we shall. That is a point that has not been developed yet. Of course, it is true as has been stated, that the great objection to shorter freight trains is a purely economic one—consisting of the extra cost of labor. Against this we have the saving in locomotive dead weight, etc., and (a point that has not been mentioned) the much smaller liability of the occurence of the expensive freight wrecks to which long trains are so subject.

One thing Mr. Steinmetz said was to the effect that unless we could run very much faster, than, say 100 miles an hour, (or the somewhat hypothetical 112½ miles, of recent rumor), that they do run with steam locomotives, there would be no object in having electricity. I think this is a mistake. There is a great deal of advantage in having electricity, even if we do not run as fast as the locomotives run. There is, however, little question but that we can run faster, because we get rid of the threshing and pounding in the reciprocating parts of the locomotive, and get a merely rotary motion, with a perfectly simple machine, instead of a rather complicated one. But we can also run faster for a given price for coal and labor, or we can run at the same speed at a less price, for one very important reason, that we get rid of the dead weight of the locomotive to a very considerable extent—the dead weight of the motor, etc., not amounting to nearly as much. And, too, we shall probably get rid of some of the dead weight of the cars which are now most abnormally heavy.

The railroads of this country are carrying passengers all over the land with from one to six tons dead weight for each passenger.[1] We cannot expect the steam railroad men, who are rather conservative, and very properly so, in the interests of their employers, to change suddenly, or adopt any very radical measures; but when a crisis like this comes, when we begin to make sudden and comprehensive changes in the way of "trolleying" old roads, the time seems to be ripe for other changes. I have no doubt, whatever, that we shall learn how to make our cars very much lighter than we do now, with a consequent decrease in cost of coal and decrease in accidents due to excessive momentum; and all this by doing away with the locomotive. Therefore we shall have an advantage, even if we cannot run faster—although I personally do not question but that we can run very much faster.

Another point that is not generally talked about is the immense advantage to passengers, and consequently much greater popularity with the public, of the electric car, because of the total absence of the soot and smoke and whistling, together with other nuisances incident to the locomotive. This is going to increase the *traveling habit* and bring in more travel than we now dream of. That it is possible by electricity to get these enormously high speeds of 120 to 150 miles an hour, as alleged in the newspaper articles referred to by our President, by the use of electricity is

1. For an analysis of this dead weight, see my article on Railway Reform in *The Forum* for January, 1891.

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probably true, considering the advantages just referred to of not having the rattling and pounding of the reciprocating motion of the present locomotive and all that, but who of us here to-night, if he had ever so nice an electric car, would like to ride over any of the tracks that we have to-day at 150 miles an hour? Possibly those without families or those with big life insurance policies might do it, but I for one should not want to. Sixty or seventy miles an hour is as fast as I care to go on these present railways, where there is nothing but a 1⅛ inch flange to keep me out of eternity.

We must, before running at those enormously high speeds, have a new system of road beds I do not know just what it is going to be, but it will, I am sure, be something vastly different from the present one. We must absolutely abolish switches and crossings and such things, as well as the presence of cattle and men on the tracks, and there must be some way of confining the cars better than by their own weight and these little wheel flanges. We shall confine them to position in some other way, so that the one great and to-be-dreaded evil of derailment will be impossible. Collisions we shall escape by the use of electric blocking, etc., and by more perfect operating systems. When we learn to avoid derailment absolutely, as well as collisions; when we get rid of our smoke and soot and our reciprocating parts, and our excessive dead weight, then, and not till then, shall we attain really high speed, combined with comfort and safety. All this the coming century will no doubt see, and probably may see rather early in its course.

President Duncan:—I have listened with a great deal of interest to the remarks that have been made. Perhaps the uses of the different methods and their limitations were correctly stated by Mr. Steinmetz. But I did not care to take the question up. I think we can offer the steam railroad people, systems that will operate their passenger traffic more economically than it is now being operated. But the question I wished to consider was whether they are in a condition to accept the offer? There are only a few roads in the United States that are in a condition to accept the electrical benefits we can give them, because no two-track road, without disorganizing its traffic, can get the advantage of electrical transportation. We cannot at present change the method of freight transportation. I am not considering what is going to happen in the future, I am considering the conditions as they exist at the present time. You cannot disorganize the freight traffic, you cannot disorganize through traffic, and with those two kinds of traffic on two tracks, you cannot possibly compete with a parallel line running a regular tramway service. It is not a question of which way we want to equip these tracks, but the thing is that the steam people must give us the tracks to equip, and to secure the benefits of electrical traction, we must have four tracks on through roads, and even with four tracks, some roads will find it difficult to equip.

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We cannot compete for freight traffic by electricity except by using self-contained electric locomotives, in which the electrical apparatus is a mere gearing between the steam and the axle. As far as the principle goes there would be no difference in the character of the service between this and the ordinary steam equipment. But a freight traffic by a trolley system will not be as cheap as the steam traffic. At the present time the condition of affairs is this: The steam roads must compete with the electric roads that are paralleling them, and which are cutting down their receipts, and I think this can only be done by giving separate tracks for the electric service, or by controlling competing roads. As Mr. Steinmetz says, there are a number of ways in which we can equip the roads electrically. Although he has projected a little into the future, yet I think he has pretty well stated the kind of service we ought to have on the different kinds of roads. But at the present moment, even if he were prepared to sign a contract for any one of the different types of equipment on any one of the different types of road, I say there are not three or four steam roads in the United States that are prepared to take advantage of it; and that was the point I wished to take up in my address.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

COMPOUNDING DYNAMOS FOR ARMATURE REACTION.

BY ELIHU THOMSON.

Considerable attention has recently been drawn to the subject of means for counter-balancing or preventing armature reaction in dynamo-generators or motors. The valuable paper of Messrs. H. J. Ryan, and Milton F. Thompson, read before the INSTITUTE at its meeting on March 20th, called forth considerable discussion as to the actual utility or need of added devices, which undoubtedly render a machine more complex, but which can certainly be made to obliterate armature reaction or overcome its effects. The opinion which seems to prevail amongst engineers is, that by taking advantage of the best principles of design, the output of our machines is not limited by armature reaction, but rather by heating, or the capacity to diffuse that heat which is sure to be produced during operation.

The writer's views are in accord with the general sentiment indicated by the discussion of the paper in question, excepting that he conceives that it may on occasion become desirable to possess a structure, either generator or motor, in which a load which would inevitably overheat the machine if continuous, may be borne without destructive results for short periods only. The development of engineering work may in fact demand, occasionally, machines which would be regarded as emergency machines, to be operated with the highest possible loads for short periods. It is sometimes desirable that a dynamo be adapted to driving at different speeds while maintaining the same potential at the terminals, as in the case of direct driven dynamos coupled

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with engines of different makes and speeds. Such an adaptation would require a change in the armature turns, or in the field excitation, the former demanding a reconstruction amounting to the production of a special type, while the latter, change of field strength, might involve such a weakened field at the higher speeds as would be incompatible with proper commutation. In such cases means and methods for securing proper commutation and neutralizing reaction may become quite useful. The subject itself has been worked upon by the writer as far back as 1879. At first a peculiar disposition of the field coils and pole pieces was selected, unfavorable to armature reactions, and later in a a patent applied for by the writer in the year 1885, the series coil of a compound-wound machine was so disposed as to add, under load, a magneto-motive force to the field in the region of armature opposition, and as a consequence to diminish somewhat the magneto-motive force of the field where the reaction of the armature was positive, or assisting.

In the present paper, however the writer desires to bring to the attention of the INSTITUTE a different type of dynamo, worked upon by him some three or more years ago, in which there is no series winding whatever, though the machine is in effect compounded, or over-compounded at will.

It is expressly to be understood at the outset that the present paper is not intended to advocate the disposition described as a desirable commercial structure, or even as one which will be likely to come into practical use on any scale. On the contrary, it is believed to be open to objections which would take it out of competition with ordinary types in which the compounding effect is secured by the series coil or load circuit wound as usual as a part of the field energizing conductor.

The machine is, however, interesting as bringing out forcibly the capability of the armature current to neutralize its own effects in a proper structure and maintain, or even increase, the potential at the brushes under heavy loads. In fact the current in the armature in the type of machine herein treated, is made to react under load to magnetize a portion of the field structure which at no load is neutral or nearly so. The reaction may thus be made to give rise to a magnetic flux sufficient or more than sufficient to compensate for its effect in diminishing the flux of the other or excited portion. The result is accomplished by dividing each field pole into a portion which is left unwound and a portion

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which is wound and excited in shunt or separately. At no load only, the wound polar portions act to generate the open circuit E. M. F. As the load is put on, the unwound or dead poles become active in consequence of a magnetic flux developed in them by the armature currents themselves, that is, in conseqence of the M. M. F. generated by the current in the winding of the armature itself. The disposition of the poles in a bipolar struc- would be represented by Fig. 1, where A A are the excited poles, or wound field cores, under the fringe of which commutation is effected, while D D are the "dead" poles or sections of polar surface unenergized at no load. A dotted line *a a* may pass through the neutral or non-polar portion of the armature iron, threaded by all field lines on one side, while the lines *b b* may indicate the diameter of commutation on which the brushes rest. In such

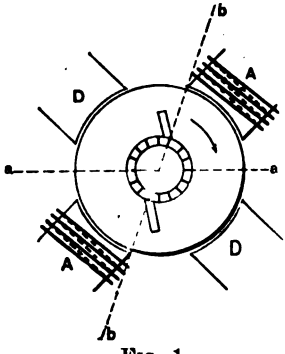

FIG. 1.

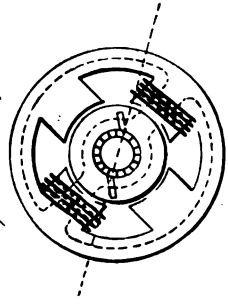

FIG. 2.

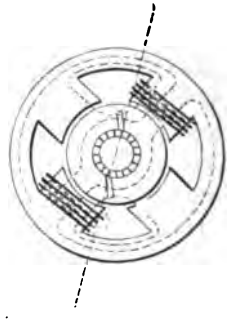

FIG. 3.

a structure by choosing the position and spread of the "dead" poles in relation to that of the wound or excited polar portions, and adjusting the M. M. F. of the initial field relatively to the turns on the armature and the speed of driving, the effect of compounding or over-compounding may easily be obtained. The "dead poles" may he made adjustable in position so as to vary the effective M. M. F. of the armature upon them and various changes in relations of the parts are conceivable.

In Figs. 2 and 3, an attempt has been made to represent the magnetic flux under no load and under load respectively. In Fig. 2 the flux in the air-gap between the excited poles A A and the armature may be considered as of uniform density except at the edges, while in Fig. 3 it is, under the same poles, somewhat diminished towards the diameter of commutation. In Fig. 2

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the dead poles are without flux across the air-gap, while in Fig. 3 the density increases from one edge to the other in the direction of rotation.

Fig. 4 is from a photograph of the dynamo constructed in accordance with the principle under discussion. It is multipolar, having four wound poles and four dead poles alternating in position around the armature. The latter is of standard iron projection type being in fact identical in construction and dimensions with the armatures used about three years ago in reg-

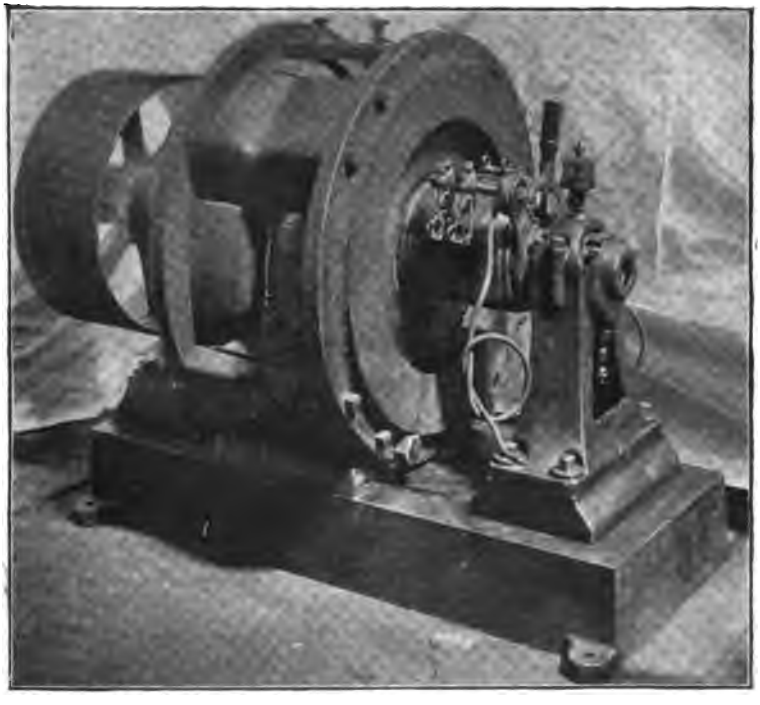

FIG. 4.

ular four-pole dynamos of the marine type of the Thomson-Houston Electric Co.

The principal data of the armature construction are as follows :

Diameter over all	17	inches.
Length (laminations)	8	"
Radial depth of laminations	4	"
No. of projections	87	
Width of slots	.34	inch.
Depth of slots	.75	"

The armature is series drum-wound and has two conductors in each slot. The commutator has 87 segments. The new field

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system was constructed of two rings of cast open hearth steel having heavy lugs, four in number, projecting laterally from each ring on one side, and forming the dead poles when assembled in the machine. Separate castings for carrying the field coils and constituting the active poles were made, wound and bolted between the two ring castings of the field. The arrangement will be understood at a glance from an inspection of Figs. 5 and 6. Fig. 5 is a section of the field in a plane passing through the dead poles and the axis of the armature, and Fig. 6 is a similar section through the active or wound poles. The wound cores have a section of $3\frac{1}{2}$ in. $\times$ 8 in. and are of steel. The field was bored to $17\frac{1}{4}$ in. thus giving a clearance of $\frac{1}{8}$ in. around the armature. The excited or wound poles covered each about 5 inches, the dead poles each $5\frac{1}{2}$ in., leaving spaces between wound and dead poles of about $1\frac{1}{2}$ in. The face of each dead pole is $5\frac{1}{2}$ by 8 in.

The coils on the active poles can be connected in shunt to the

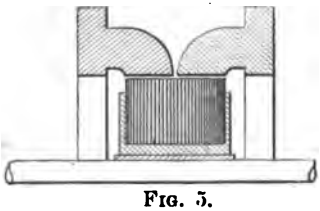

FIG. 5.

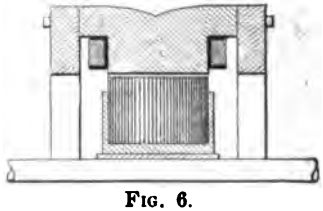

FIG. 6.

armature terminals with a variable rheostat in the branch, or separately excited as desired. It was found that for the purposes of test that the latter arrangement was most satisfactory as the exciting current could then be adjusted to any given value and would remain undisturbed by variations in the potential difference between the brushes or terminals of the machine.

Fig. 7 shows the relation of volts at the terminals to varying exciting current at no load (full line) and at 30 amperes load (dotted line) with a speed of 800 revolutions per minute. It will be noted that the load has caused an increase of voltage particularly at the relatively higher excitations. The normal current of full load for the armature as constructed and used in the regular multipolar field was 140 amperes, and it was found that as the load was increased steadily during a run, the potential was not only maintained but increased with each increment of load, thus showing an over-compounding effect. This effect was less marked

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when the initial excitation was weak; as when less than three amperes traversed the field coils. The over-compounding under load was, of course, still more increased when the field coils were connected in shunt to the armature. Thus, at a little over 750 revolutions per minute with an exciting current of four amperes, the open circuit volts were 84, rising to 104 when a load of 130 amperes was put on with an increase of the exciting current to 4.8 amperes.

It was noticed that on any considerable increase of load being made, the potential rose in some cases as much as 5 or 6 volts

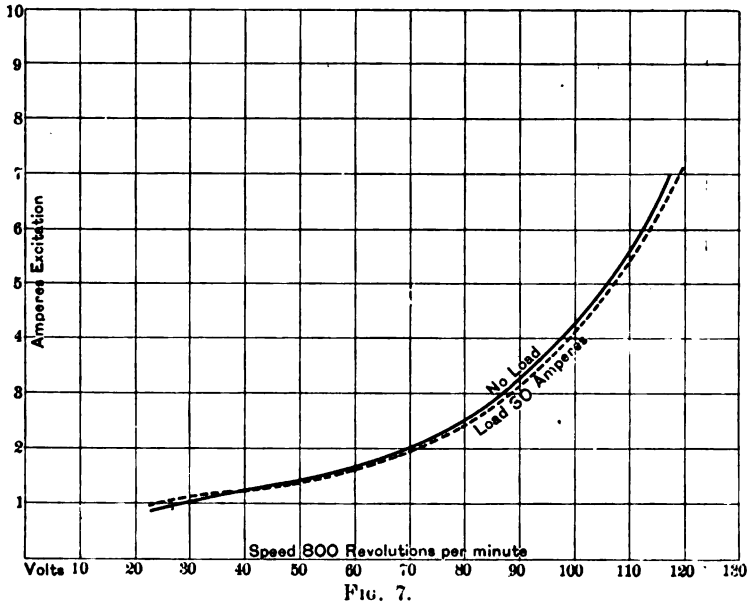

Fig. 7.

above the point at which it would remain; or which it would reach after a short interval. Similarly it was found that the sudden taking off of load caused a temporary fall below the stable voltage under the new or diminished load conditions. This curious effect was traced to the difference of time between that needed to build up or cut down the flux in the dead poles, as compared with that required to cut down or build up the excited poles, which, being wound with wire, were naturally more sluggish under the conditions of use. Currents would be induced in the coils under each change of flux, which change itself would

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thereby be rendered more gradual. The dead poles being unwound could respond more rapidly. Any increase of load would of course tend to break down the wound poles and to increase the flux in the dead or unwound poles, and the taking off of load would have the opposite effect.

Fig. 8 shows a compounding curve obtained under a constant excitation of four amperes at a speed of 790 revolutions, the load being varied from 0 up to more than thrice the full load. It will be noticed that the potential at first increases, and only breaks down under extremes of load. The final breaking down

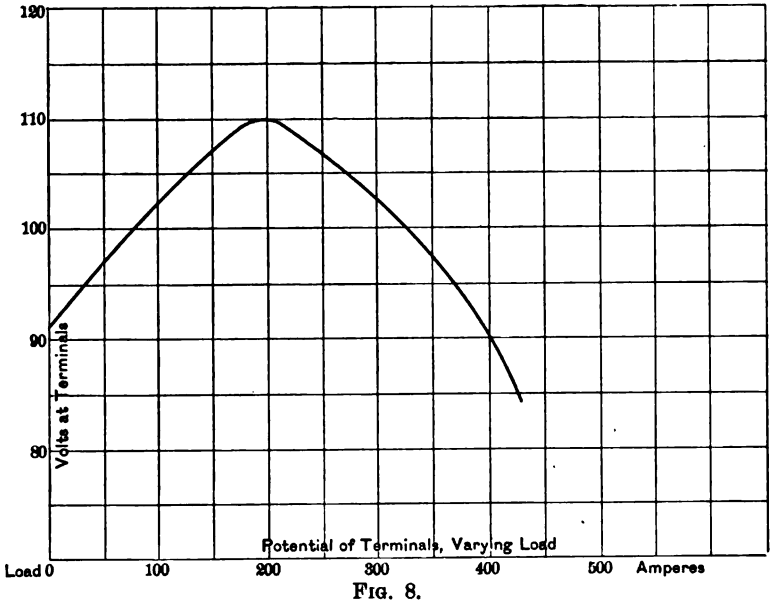

FIG. 8.

is doubtless due to saturation of the forward portions of the dead poles, together with the armature core projections. Part of the drop was undoubtedly due to resistance at the brushes which were of carbon, and by no means fitted to conduct off such heavy currents. Taking this drop and the drop over the armature conductor itself, it is not surprising that at the high loads the potential should fall off.

A horizontal plotting of the potentials generated in the armature coils under no load obtained by the two brush method of Dr. S. P. Thompson, is given in Fig. 9, the relative positions of

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the wound and "dead poles" being marked in dotted lines, and the arrow indicating the direction of movement of the armature relatively thereto.

Fig. 10 gives the same plotting under a load of 100 amperes and accentuates the effect of the armature reaction in magnetizing the dead poles. The curves are only approximate indications

FIG. 9.

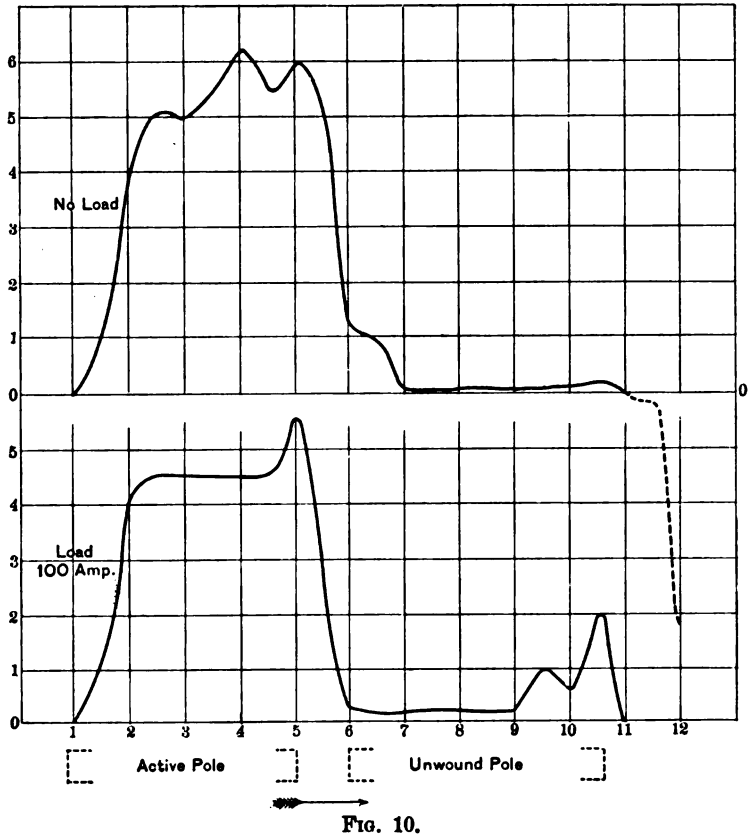

FIG. 10.

owing to the fact that the number of points at which readings were taken was less than was desirable, and because in some cases it was difficult to maintain all conditions unchanged, particularly with the very heavy loads.

Figs. 11 and 12 show a similar plotting for abnormal or extreme loads. The former shows how completely the wound pole has

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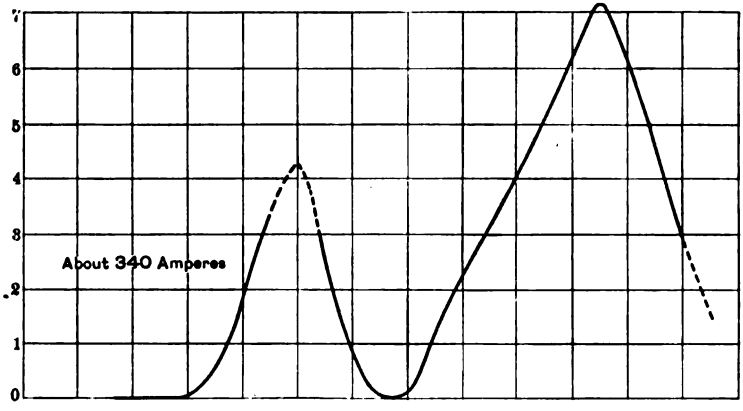
been broken down by armature reaction, and how the unwound poles have now become the chief working field poles, or rather how the armature winding itself has furnished the field for its own cutting. A calculation of the flux density at the forward edge of the unwound pole shows that the magnetization has risen to saturation. The other parts of the pole are shown to be still

FIG. 11.



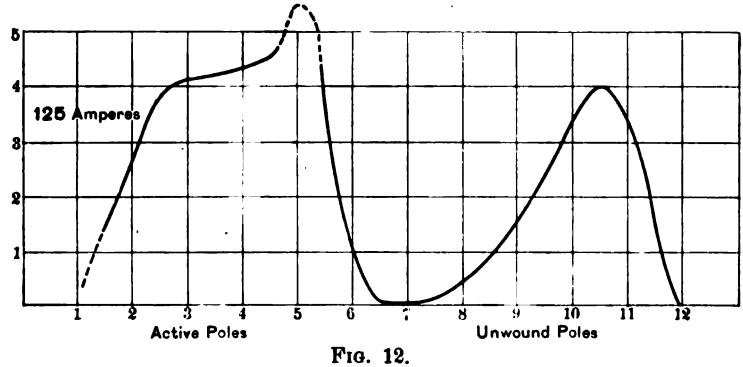


FIG. 12.

susceptible of increase of flux, but their relation to the armature is far less favorable for its generation.

The machine described is probably chiefly interesting from a theoretical aspect. Still it shows clearly that so far as the effect of the series field on compound wound machines is concerned, the electrical engineer has other resources at his command giving similar results. It cannot be doubted also that the design of armature and field might be considerably improved with special

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regard for the particular feature of compounding. A feature of the machine which developed itself when carbon brushes were used, was that even at heavy loads the brushes could be set back from their maximum position, or true diameter of commutation in this case, and that the movement was attended with little, if any increase of spark, while the potential steadily went down. It was thus easily possible to adjust the potential by a backward movement of the brushes in the space between the unwound and wound poles, while the slight sparking under the carbon brushes was not increased thereby. The writer has never noticed this effect in so pronounced a degree in any other structures, but thinks that it may not be peculiar to this machine.

A further interesting consideration is the effect of dispensing with the wound poles altogether, and either neglecting to employ any reversing or commutating field while maintaining the brushes near the forward edge of the field poles which now remain, namely, the unwound poles, or employing commutating arrangements similar to those used by Mr. Sayers; that is, returning the leads through slots in the armature under the strong induction of the forward edge of the pole as the armature leaves it. In such a case it would appear from theoretical considerations that the machine should, if it possessed any permanent magnetism, excite itself as a series dynamo entirely without any winding on the field and solely by the action of the armature winding itself. This fact was, I believe, first pointed out by Drs. J. and E. Hopkinson.

In conclusion it may be stated that tests of the machine used to generate single phase and three phase alternating currents in its armature winding were made by dispensing with the commutator and substituting rings and connections common in such cases. The results indicated a substantially similar effect of compounding, but to a less degree, owing no doubt to the fact that the phase of the electro-motive-force generated by the wound pole flux would not coincide with that due to reaction on the dead poles, since the position of the poles with relation to any portion of the moving wire is different at the same instant.

The Secretary announced that the American Telephone and Telegraph Co. [long-distance] had extended to the members of the Institute the courtesy of their lines throughout the United States during the continuance of the meeting.

[Recess until 10 A.M.]

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A paper presented at the 12th General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

ELECTRIC POWER IN FACTORIES AND MILLS.

BY F. B. CROCKER, V. M. BENEDIKT AND A. F. ORMSBEE.

INTRODUCTION.

The application of electric power distribution to the operation of factories and mills, including the driving of the various machines and other apparatus, is the latest and one of the most important problems toward which attention is now being directed, the question being one of extreme prominence both from an economical as well as from an engineering standpoint.

In comparing two or more different systems of power distribution, the fundamental basis of comparison is generally that of dollars and cents. This is certainly correct, as far as it goes, but unless a very decided difference be found between the costs of running under the various systems, it may be found that other factors enter; factors which cannot be estimated in dollars and cents, namely, questions of desirability and convenience. Without considering any tests whatever, there are several exceedingly advantageous points in the use of motors in factories which are almost self-evident, such as: 1. Clear and unobstructed passages and head room, the latter facilitating the use of travelling cranes. 2. Ease of shifting the tools from place to place, possibly necessitating the placing of a starting box and the putting up of a little extra wire, as compared with the inconvenience and trouble of setting up and adjusting a line of shafting, hangers, belts, etc. 3. The economy due to the ability to run a single tool without necessarily starting the whole factory or at least a complete section. 4. The running expense is entirely stopped when the tool is shut down. 5. The absence of the drip of oil from overhead shafting. 6. The tools may be placed at any desired points

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almost regardless of the distance. 7. It is not necessary to arrange the tools parallel as in the mechanical system. 8. A wider range of speed is possible. 9. Less damage caused by a fuse blowing, than by a belt slipping off in case of accident or excessive load.

Considerations like the above have great weight in deciding a question such as that under discussion, and there is no doubt whatever that in most cases they rise to such prominence that they warrant a complete change from the old system to the new, even though there is no gain in economy or increased output. In most cases, however, it has been conclusively shown that considerable saving and increase in production is obtained, one test showing a very considerable percentage of increase in the output. The partial, if not the complete, displacement of the old method by the new is only a question of time, and it was the appreciation of this fact that induced the authors to undertake the determination of the power actually required to run the various tools and machines as used in ordinary practice.

Historical Notes.

The general use of electric motors in factories is comparatively recent, hence the history of the subject is necessarily short, although Froment, about 1850, used an electric motor to drive tools in his workshop. About five years ago motors were in operation in the works of the Thomson-Houston company at Lynn, the Crocker-Wheeler company and the C. and C. company. Shortly afterward the great German works of the Siemens and Halske company and the Allgemeine Elektricitäts Gesellshaft began using motors to operate sections of their factories. From that time to the present, the use of motors has extended rapidly, until now they have been adopted in many factories all over this country and to a less extent abroad.

Practical Tests.

In the tests which follow, the power required to drive the tools was obtained by placing an ammeter in the circuit of the motors running the various machines and groups of machines, and taking readings every few seconds, the frequency of the readings depending upon the nature of the tool and the work it was doing. The potential was practically constant at 110 volts, not varying more than one or two per cent. The first tests were made at the factory of the Crocker-Wheeler Electric Co., at Ampère, N. J., and the machines tested and the results obtained were as follows:

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1. *Large Boring Machine.*—This machine was driven by a 1½ H. P. motor, speed 1,200 R. P. M., mounted directly on the frame of the tool, the reduction in speed being obtained by the use of gearing. During this test, which lasted three hours, the machine was used for turning down a commutator for a 100 H. P. dynamo. The average current drawn was 8.3 amperes, representing 1.23 H. P. at 110 volts. Before the run was finished, the speed of the tool was increased by changing the combination of gears, and during this time the power required was 1.43 H. P. When the machine was started from rest, the rush of current was considerable, the average being 17.75 amperes, representing 2.6 H. P. It will be seen that this motor is well suited to the machine, the average load being very close to the rated power of the motor.

2. *Drill Press.*—A drill press was run by a 1 H. P. motor, speed 545 R. P. M., mounted on a shelf at top of press and belted down to countershaft at bottom, and thence up again to main shaft of machine, thus securing a reduction of the speed. This machine was boring the faces of the cast-steel pole-pieces of a 10 H. P. motor, two cutting tools being used. The test lasted 4 hours and 40 minutes and during this time the pole-pieces for three motors were bored. The first run covered 1 hour and 10 minutes and the average current was 2.92 amperes, representing .43 H. P. It required 15 minutes to replace the completed pole-piece by another one. This second piece required 2 hours and 32 minutes to finish, and the average amperes were 2.82 or .41 H. P. This time it required 17 minutes to replace the piece, and then the machine ran only 23 minutes until closing time. The current for this short run was 2.81 amperes, representing .41 H. P. The total length of time the machine was running was 4 hours and 5 minutes. Therefore power was supplied to the motor 86 per cent. of the time of the test.

3. *Drill Press.*—This machine was similar to the one preceding, but the work was different; namely drilling half inch holes in cast-iron bearings. The average current was 2.86 amperes, which represents .42 H. P.

4. *Drill Press.*—This tool was the same as the other two and the work consisted in boring the inside of cast-iron bearings. The average in this case was 1.9 amperes or .28 H. P. It will be noticed that in the case of these three machines a motor of one-half H. P. would be of ample size to do the work.

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5. *Punch Press.*—This was a small punch run by a one H. P. motor mounted on the base of the machine and belted to its heavy fly-wheel. The speed of the motor was 700 R. P. M. This tool was punching slots in sheet iron disks for a 10 H. P. armature, there being 28 slots in each disk. The motor was turned off every time a disk was replaced, but it did not come to a dead stop as the inertia of the fly-wheel was so great. Readings were taken every five seconds and the time of turning on and off the current was noted. The test lasted 57 minutes, during which time the current was turned on for 35 minutes and 45 seconds, or 62.7 per cent of the time. The average current was 4.86 amperes, equivalent to .71 H. P. The rush of current at starting varied from 7 to 15 amperes, depending upon the haste of the workman in turning on the starting box.

6. *Gang Drill.*—This tool was driven by a one H. P. motor, 1,000 R. P. M., mounted with vertical shaft in frame of the machine and belted directly to the three drill spindles. The material drilled was cast-iron, and the sizes of the holes were ¼ in. and ⅜ in. The average of the readings taken was 4.75 amperes or .7 H. P. When the drills were running free the motor took 3.5 amperes. Thus the power required to overcome friction was 74 per cent. of the power used while drilling.

7. *Group of two machines, one lathe and one milling machine.*—This group was driven by a three H. P. motor, belted to a short line shaft, from which belts ran to the countershafts above the two machines. The average current was 10.04 amperes, the power being 1.48 H. P. In this test, special attention was paid as to which machine happened to be running free, cutting, etc., with the results given in the following table.

Class of Machines and Work.	Amperes.	H. P.
Milling Machine Running Free—Lathe at Rest	5.67	.836
Lathe " " " —Miller " "	7.36	1.085
Both running free	10.	1.47
Milling Machine Cutting—Lathe run free	10.33	1.52
Lathe Cutting—Milling Tool running free	14.42	2.12
Both tools cutting	15.4	2.28
Cutting rate increased on the lathe	17.8	2.61

8. *Group of Six Machines, Consisting of* 1 *Milling Machine* (*Small*) 2 *Lathes* (10 *or* 12 *Inch Swing*), 1 *Grindstone*, 1 *Drill Press and* 1 *Small Punch Press.*—The last named tool was not run at all during the test, and the grindstone ran continuously. This group was run by a one H. P. motor, belted to the usual

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ceiling line shaft. The average current required to drive these machines was 5.86 amperes, representing .86 H. P. Thus this motor ran at about its most economical load.

9. *Group of Seven Machines*, 1 *Planer*, (*Small*) 1 *Grindstone*, 4 *Lathes*, 1 *Hand Turning Lathe*.—A three H. P. motor was used to drive this group, being belted to a line shaft, the same as the previous groups. The current was 13.36 amperes or 1.97 H. P. When the entire group was in use 2.65 H. P. were required.

10. *Group of* 7 *Lathes and* 1 *Grindstone Driven by a* 3 H. P. *Motor*.—The average current was 9.92 amperes and the power required was therefore 1.46 H. P. The power used by the motor when different numbers of lathes were running is shown by the following table:

Number of Lathes Running.	Amperes.	H. P.
One	7.76	1.14
Two	9.16	1.35
Three	10.69	1.58
Four	12.23	1 8

Thus in a group like this, it only takes 63 per cent more power to drive four lathes than it does to run one, the reason being the fact that it probably takes about one horse power to drive the countershafts.

11. *Group of Two Machines, a Large Punch Press and a Large Planer*.—The motor for running this group was placed on the floor, and drove a short line shaft on the ceiling by the usual form of belt. The rated capacity of this motor was 7½ H. P., and its speed was 1350 R. P. M. The punch press did not run during the test. With the planer idle and the motor driving the shafting and belting alone, the current was 15.5 amperes, which represent 2.3 H. P. While the planer was at work the motor required 33.1 amperes or 4.87 H. P. As the loss from friction in the shafting is nearly constant under the variation of load, the power required to overcome this friction was 47 per cent. of the total power used. When the bed of the planer reversed from its slow cutting stroke to the comparatively rapid return stroke, the current increased to 52 amperes, showing an expenditure of 7.6 H. P. for a few seconds. This tool was planing the frame of a 90 K. W. multipolar dynamo, the material being cast-iron.

12. This group was a very large one, consisting of 20 machines;

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8 lathes, 4 milling machines, 3 planers and shapers, 2 grindstones, 1 vertical shaft grinding machine, and 3 small tools. The motor in this case was rated at 10 H. P. at 750 R. P. M. A Thomson recording wattmeter was placed in the circuit of this motor for one afternoon. At the end of this time the wattmeter showed a total of 17,854 watt-hours used, and as the time was five hours, the average power was 3,571 watts or 4.78 H. P. The average number of machines running was 13, most of the lathes being in use the greater part of the time. An ammeter was inserted in the circuit of the motor for a few minutes, and it was noted that the work was very steady, the current not varying more than 3 or 4 amperes at any time.

13. A group of five machines run by a 3 H. P. motor was next tested. Of these five machines, one was a lathe with 17 inches swing and 8 feet bed, one was a slotter, and the other three were lathes of 12 or 14 inches swing. The average amperes were 7 and the power 1.03 H. P.

14. The last tool tested at this factory was a large new engine lathe, which had just been set up, of 50-inch swing. This tool was driven by a 3 H. P. motor mounted on an iron bracket built in the base of the machine. The motion of the motor shaft is transmitted to the tool by gears, thus doing away with all belts. The work done was turning a 5½-inch steel shaft for a 200 K. W. dynamo, facing the ends etc., the cut being very light, as the work was only preliminary. The average current consumption was 11.4 amperes. Hence the average power was 1.68 H. P.

The following tests were made in the erecting shop of the De La Vergne Refrigerating Machine Company, at Port Morris, N. Y.

1. *Planer.* A large planer, 120 inches between posts, by 108 inches high, by 22 feet bed was driven by a C. and C. motor of 15 H. P. The voltage employed was supposed to be 220, but due to an incorrect station voltmeter the actual potential only averaged 190 volts on the morning of this test. The average current was found to be 20.08 amperes which at 190 volts represents 5.11 H. P. At the reversal from the cutting to the back stroke, the current increased to 85 amperes, equivalent to 21.65 H. P. The power required during the cutting stroke was 4.76 H P., while on the return stroke the average was 5.73 H. P.

2. *Drill Press.* A drill press driven by a 5 H. P. C. and C. motor was tested in the afternoon. The potential was raised be-

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fore this test, so that the average was 215 volts. The power required when drilling variously sized holes is shown in the following table:

Size of Drill.	Amperes.	H. P.
Running Free.	3.	.865
$\frac{7}{16}$ in.	4.07	1.23
$\frac{21}{32}$ in.	4.37	1.26
$\frac{31}{32}$ in.	4.6	1.33

3. *Corliss Cylinder Boring Machine.* This tool was driven by a 10 H. P. C. and C. motor and was boring the brass boxes, $6\frac{3}{4}$ in. diameter, of the main shaft bearing of a large ice machine. The average current was 14.47 amperes, representing 4.17 H. P. at 215 volts.

In order to place the results in a more convenient form the following table of average powers was compiled.

TESTS AT THE CROCKER-WHEELER FACTORY.

No. of Test.	Size of Motor.	Number of tools driven by motor.	Average Amperes.	Average horse power.	Remarks.
1	1.5 H. P.	1 boring machine.	8.3	1.23	
2	1. "	1 drill press.	2.85	.42	Less than ½ full load of motor.
3	1. "	1 " "	2.86	.42	
4	1. "	1 " "	1.9	.28	
5	1. "	1 punch press.	4.86	.71	
6	1. "	1 gang drill.	4.75	.7	Drilling ¼ in. and ⅜ in. holes.
7	3. "	2 machines.	10.04	1.48	
8	1. "	6 "	5.86	.86	All small machines.
9	3. "	7 "	13.36	1.97	
10	3. "	8 "	9.92	1.46	
11	7.5 "	2 "	33.1	4.87	Required 2.3 H. P to run shafting only.
12	10. "	20 "		4.78	Tested by wattmeter.
13	3. "	5 "	7.0	1.03	
14	3. "	1 engine lathe.	11.4	1.68	Light cut taken by tool.

TESTS AT THE DE LA VERGNE WORKS.

1	15. H. P.	1 planer.	20.08	5.11	Planer 10 ft. x 9 ft. x 22 ft. Voltage 190. ⅞ in. drill.
2	5. "	1 drill press.	4.07	1.23	Voltage 215.
3	10. "	1 boring tool.	14.47	4.17	Voltage 215.

The results obtained in these tests show that the power required to drive machine tools has been considerably overestimated, for it will be noted that with a large majority of the tools tested, the motor was not more than one-half loaded, and in

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these cases it was seldom that the load equalled the full power of the motor, even for an instant. In the case of the large planer, although the motor was overloaded 50 per cent. upon reversal of the bed, the average load was only one-third of the rated full load. With this machine, however, when the piece of work is very short, necessitating more rapid reversals, the average load will be much nearer the most economical output of the motor.

The question of running machine tools by individual motors or grouping a number of machines together and driving them by one motor, does not seem to allow of a general solution. It would not be advisable, for example, to use the individual system where there are a number of small tools, each one of which requires only a small fraction of a horse-power. On the other hand if we have a large tool that requires considerable power, it would seem to be far more economical to run it by a single motor, using as little belting and shafting as possible.

Many of the manufacturers of machinery are now supplying boring mills, punching presses, drill presses and other machine tools arranged to be driven by electric motors. In most cases all that is necessary is a shelf or bracket on the tool to support the motor, and a gear wheel in place of the main pulley, unless a belt connection is preferable. A press or other tool having a large fly-wheel may be driven very conveniently by cutting teeth on the edge of the wheel which gear with a pinion on the motor shaft.

Electric Power in the New England Cotton Mills.

The introduction of the electric system of distribution of power in the cotton industries of New England is now fairly begun. Although there are no large mills driven entirely by this system, a number of them have an electric plant and certain sections of the mill are driven by motors. An electric plant was installed four or five years ago in the works of the Silver Spring Bleaching and Dyeing Co., at Providence, R. I., but it was intended chiefly for lighting. But motors were placed in the carpenter and repair shops, and several other places, until at present there are about 100 H. P. of motors installed in eight units. The generating plant consists of three 100 H. P. U. S. dynamos belted together from a countershaft which is driven by a Corliss engine. Two of the machines are 110-volt dynamos which are used for lighting and running most of the motors at present. The third machine which has just been installed is a 500-volt Westinghouse power

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generator of the same type as the lighting machines. There is only one machine at present connected to the 500-volt circuit, a 30 H. P. motor which drives a centrifugal pump supplying a storage reservoir with water for use in the bleacheries. The electric plant in this mill is not of much importance yet, but its chances for development are very bright since there are a number of machines now run by individual steam engines. These could be most advantageously replaced by electric motors as they are in some cases a great distance from the boilers, involving large losses from condensation.

A visit was made to the works of the Dunnell Manufacturing Company, at Pawtucket, R. I., where a very fine electric plant has very recently been installed to drive the calico printing machines. The problem of running this class of machinery by electric motors has been a very difficult one to solve, for the motor must be capable of running at a number of different speeds, and running constantly at any given speed with a variable load. In this case it has been solved by the use of a modification of the Leonard system of motor regulation. The outfit for each printing machine consists of a motor and a dynamo of the same size, the field rheostat of the dynamo being placed alongside the printing machine. The speed of the motor is thus changed by varying the voltage of the particular dynamo which supplies it with current.

The dynamo room contains eleven dynamos of the new moderate speed, four-pole type, made by the General Electric Company. They are run by a Corliss engine through a system of belting and ceiling countershafting. Six of these are 20 K. W. machines and four are 25 K. W. The eleventh dynamo is a similar 20 K. W. machine used for exciting the fields of the other dynamos. The normal potential is 250 volts, and is lowered in any particular dynamo when slower speed of the motor connected to that circuit is desired. This plant has been completed but a short time, and it was not possible to obtain any accurate figures showing the power used by the motors under various conditions of speed and load. Formerly the machines were run by individual engines and much difficulty was experienced in starting them, as the pressure of the printing rolls against the cloth is so great. With electric motors this difficulty is overcome, as the motors will stand a very heavy overload for a short time, and the starting torque is very great. The great advantage of the electric system as here used, is not so much in the saving of power as in the convenience to the workmen, and hence the increased production.

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The saving of power, however, is quite considerable as in the old system steam was piped several hundred feet to the small individual engines, which were necessarily inefficient under the best conditions, and added to this the engines were run part of the time with partly closed throttle, still further decreasing the efficiency. With the present system, the attendant at the machine may quickly vary the speed to any required extent by turning the rheostat near the machine.

Although this plant has been in operation only a short time, it is claimed by those in control that the production is materially increased. In a paper by Mr. S. B. Paine in *Power*, June, 1895 he states that the increase in the production amounted to more than 25 per cent., and that the quantity of "seconds" (inferior product) was also considerably reduced.

This is very important, as the men in charge of printing machines are skilled workmen of the higher order, and a small saving in wages for a given production is of more value than a considerable saving of power.

A visit to Baltic and Taftville was also made to see the practical working of the well-known power transmission plant between these places. At Taftville, where the Ponemah mills are located, there is not sufficient water power to drive all the machinery, so an electric plant was installed at Baltic, 4½ miles up the river where a dam had been built, giving an available head of 34 feet. The wheels are horizontal balanced turbines, two of them being rated at 800 H. P. each, while the third one is rated at 300 H. P. The wheels are belted to a long line shaft, which is in turn belted to the dynamos. The generators, of which there are two, are placed in a separate room. They are of the three-phase General Electric type and are capable of supplying 250 K. W. at 2,400 volts. They have ten poles and run at 600 R. P. M., giving a frequency of 50 cycles per second. The field is excited by a 3 K. W. bipolar dynamo belted from the generator shaft. The power is transmitted to Taftville by a very well constructed pole line. The motors are located in the basement of the Ponemah mill near the engines which they replace. They are belted to pulleys which are connected to their respective shafts by friction clutches in order to enable the motors to be started without load, as they are of the synchronous type. The motors are identical with the dynamos except in having an induction winding of heavy bars sunk in the pole-pieces, to cause them to be self-starting. In starting the

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motors, the switch in the induction circuit is closed and then the line is connected to the armature, causing it to start as an induction motor, without a very great torque, however. When the motor has nearly reached full speed, the field is excited and it will speed up until it falls into step and then the induction switch is opened. This method of starting has two advantages: first, no auxiliary motor is needed; second, no device is required to tell when the motor is in synchronism with the generator.

One of these motors drives 1,200 looms requiring an expenditure of about 155 H. P. The other drives 500 looms and also the railway generators for the Norwich Electric Railway Co. The introduction of this plant has enabled the company to concentrate all its power for use in one mill, tending to decrease the cost of production, diminishing transportation charges and avoiding the use of any coal for steam power.

Conclusions.

First Cost.—Practically the only objection which can be urged against the electric system is the fact that the first cost of installation is greater than with ordinary belting and shafting, but even this is questionable, since the authors know of cases in which the estimated total cost of installing the necessary belting and shafting was actually greater than the equivalent electric motor outfit. The electric system would be cheaper for example in the case of very long or scattered buildings or those containing many stories or rooms, in any of which cases the belting and shafting required would be very complicated and expensive. The use of belting and shafting requires a much stronger and more expensive roof or ceiling than the electric system.

Saving of Power.—It might seem that the electric system would actually consume more power than the ordinary plan since it involves two transformations of energy. In most cases, however, if the power has to be distributed to a number of machines, particularly if they are located at any distance from the engine, the loss of power is less with electric transmission. This is explained by the high efficiency of the dynamo and motor, compared with the low efficiency of belt transmission as ordinarily practiced, involving as it often does very imperfect alignment and lubrication of the shafting. Perhaps the greatest saving, however, of the electric system is due to the fact that the consumption of energy entirely ceases when the tool stops. This

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stoppage in the case of the busiest tools, amounts to at least 25 per cent. of the nominal working hours throughout the year, and with large or special tools which are not used so steadily, the stoppage is often as high as 50 to 75 per cent., since there are many whole days when they are not used at all.

Idleness due to strikes as well as to slack times must also be considered, and would usually amount to quite a large percentage in ten years for example. This assumes, of course, that a portion of the shop is running, which is usually the case even under such conditions. In short, with the mechanical system there is an enormous amount of shafting, idle pulleys and belting which run for long periods of time doing little or no useful work, but consuming considerable power.

Wherever electric motors can be substituted for a number of small engines scattered about, the saving in power is very great not only because of the low efficiency of small steam engines, but also by the avoidance of condensation in long steam pipes.

Increased Output.—This is, perhaps, the most important advantage gained by the electric system, since after all the cost of power is a very small item, being, according to Mr. Richmond,[1] only about 1 per cent. of the wages paid in average machine shop practice.

This increased output is secured by the greater convenience and promptness in starting and stopping as well as in regulating the speed of the machinery. The workman can, for example, temporarily increase the speed when the conditions are favorable, thereby saving considerable time.

Flexibility. The great convenience of moving the tools and placing them in any desired position is another special advantage of the new system. The great adaptability of this system is particularly well shown in the case of a factory which was almost completely destroyed by fire, nevertheless a few uninjured tools in a remote end of the building were operated successfully by means of electric motors within two days after the fire.

Speed Regulation.—The ordinary type of motor used in factories is the plain shunt wound machine, fed with constant potential current. The motor is started and varied in speed by means of a rheostat in the armature circuit. This simple arrangement answers very well in most cases, but for variable speed between

1. *Engineering Magazine*, January, 1895.

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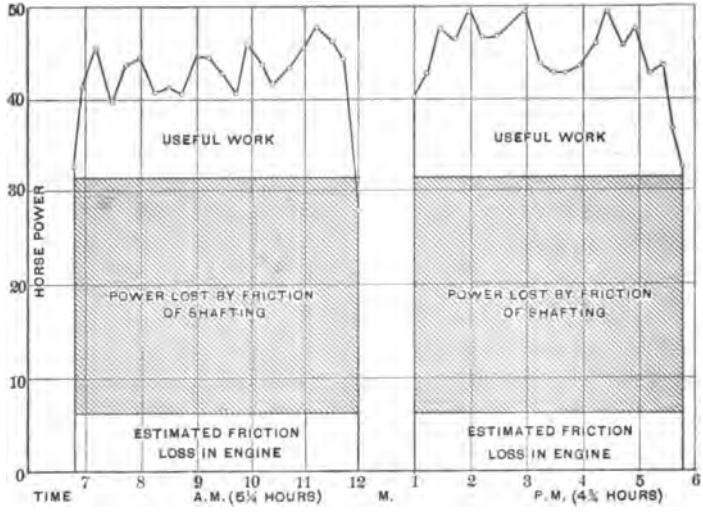
wide limits, a series wound motor controlled by a rheostat as in electric railway practice may be preferable. In other cases some special method of regulation such as the Leonard system, or the "boost and retard" plan may be adopted.

In concluding, the authors wish to express their sincerest thanks to the various companies for the courtesy shown by them and for the kind assistance which they rendered during the tests.



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Discussion.

The President:—I think that Dr. Crocker's apology for presenting exact data is not necessary, as that is precisely what we want. Opinions are valuable, more or less, according to the persons they come from. Exact data is always valuable, and in a new departure of this kind it is especially useful to us, and the data given here is certainly of great value to any one who is connected with machine work. The paper is open for discussion.

Dr. C. E. Emery:—This paper is of great value. Without question the electric motor should play an important part in shop transmission. The extreme view originally expressed that a motor should be applied to every tool, is modified by the illustrations here presented, though unquestionably there are many tools which should be thus driven independently. For tools that are used occasionally it is wasteful to keep a belt running, particularly in an out-of-the-way corner where a long line of shafting must also be kept in motion. An electric motor is desirable in such case as well as to operate tools which are at times used during the night. There are also many tools of which the speed is required to be changed frequently, which can be most economically and most satisfactorily operated by an electric motor. There are, however, advantages in having some of the tools grouped together, for the reason stated in the paper, that the power required for the group is much less than the sum of the powers required to operate each separately. Properly arranged groups therefore require a less number of motors, and motors of less aggregate power, and moreover the larger motors are proportionably cheaper so that a considerable saving of interest is secured to balance the comparatively small losses due to running short countershafts. These considerations are not arguments against the desirability of using independent motors on certain tools, but show the necessity in this, as well as in all branches of engineering work of considering the conditions for each particular case.

The electric method of transmission has become of great importance in the distribution of small powers in our large cities. In the lower part of New York it is very common to have warerooms and small shops in the same loft. With the old system long shafts were run underground and through various buildings with belts leading in all directions, and in many such shops the rattle of the machinery could be distinctly heard. Now, in many such places, small motors are substituted requiring little care, and

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the noise is so far decreased that it is hard to realize that manufacturing is being conducted in the same room. The facilities for working overtime are very greatly increased, as it is no longer necessary to make charges for keeping long lines of shafting in operation and, indeed, when the current is taken from the street, service is on tap all the time and the expense ceases when the work is stopped. Such a power transmission practically makes whole blocks of buildings part of a large manufactory, and the advantages of the system are equally applicable in regular shop practice. We are particularly to be congratulated in having the facts stated in relation to the different methods of installation, and the same will prove very valuable in laying out future plants. I feel very grateful to the authors of the paper for the clear presentation they have given us of the subject, and particularly for the very valuable facts they have presented.

Mr. H. Ward Leonard:— I have some familiarity with the plant that the authors have mentioned, that has been installed at the works of Dunnell and Co., at Pawtucket, R. I., and as it is a pretty good sample of the superiority of the electric motor over steam engines for practice of that kind, it may be interesting to give the facts in connection with that case. These presses for calico printing are quite large affairs. They take about 30 H. P., and formerly there was a throttling engine connected with the press, and by operating the throttle the speed of the press was regulated by the operator, for each particular press. The torque of the engine was not sufficient to enable them to start the press up from rest except by the aid of a pinch bar, which was used by the operator to add to the torque. The presses have a large number of rolls which are arranged in a circular frame and these are set down by pressure upon a blanket sort of an affair, so that the pressure upon the rolls and the number of rolls set down will determine the torque. The electric motors that were put in there at first were of the plain shunt-wound type, with a rheostat in the armature circuit. I think it may be well to point out the conditions with a shunt-wound motor and a rheostat in the armature circuit. Suppose that we have the armature so running that it is at one-tenth its full speed, so that about nine-tenths of the total voltage of the line is dropped upon the rheostat and one-tenth is upon the terminals of the armature. If now, under those conditions, the torque and consequently the current be increased 10 per cent., the entire drop of voltage will be upon the terminals of the rheostat, and the motor will come to rest. Therefore any slight variation in torque in a motor controlled by a rheostat at slow speeds makes its movements extremely erratic, and it is impossible to obtain any kind of satisfactory results. In a case like this printing press, where the torque was quite variable as the press went around, due to variations in the thickness of the blanket, etc., that method of operation was not a success, and they then used the plain series-wound motor, and with the same

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difficulties, and even more marked. Then a commutated field motor was employed, and finally a very strongly accumulatively-wound compound machine was used, and none of the results were satisfactory, and I made an application of my method of exciting the motor field constantly, and then varying the strength of the generator field, which is also separately excited, and we were able to get perfect control of the speed and practically unlimited torque. We were able to start without any difficulty—without any outside assistance, and one point which was rather impressive to the steam engineer present—the Westinghouse-Church-Kerr Company were the parties who were putting in the steam plant—and Mr. Church was there. When I succeeded in operating the press satisfactorily, operating it at variable speeds, and he saw the very enormous torque which the motor was developing in starting, he stated that while I seemed to be able to get the press going, he had no such surplus power in his engines as would permit of such a very large load being suddenly thrown upon them; and when I explained that while the torque was very large, yet the energy was quite small really, on account of the low voltage employed in starting; he said that he would not attempt to discuss the subject theoretically, but that as he had an indicator on his engine at that time, that he would take diagrams if I would start the press up at its slowest speed half-a-dozen times, and he would find out how much power was indicated. So the press being about 600 feet across the yard from the engine house, we set our watches together and at a certain time I started the press about half-a-dozen times or more, and he kept the pencil down on the diagram taking the card. Then we waited, and in the course of half-an-hour word came over to us to ask why we had not started up. The fact was that he had an engine running at about 75 H. P., and the additional power of starting the press was so trifling that he thought it was just the usual slight variations of the cut-off of the engine and did not think the press had been started at all. That shows the amount of starting power that would be required in such a case as that. Last July I saw the original press that I put into operation about three years and a half ago. The generator was a regular old bi-polar Edison machine of about 25 K. W. with an exactly similar motor, and it had been running in regular service for about three years and had copper brushes on the generator, which I was rather surprised at, as I thought they would probably have changed them to carbon before that time. But there was no evidence of wear upon the commutator, or sparking, and the result, according to the operators of the press, was quite satisfactory.

Another application that I think of in connection with machine driven tools, which some of the members of the INSTITUTE saw, and has been used considerably by William Sellers and Co., is in connection with large boring machines for boring, drilling and tapping the heads of boilers and things of that nature, where it is

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desirable to secure a large number of different automatic speeds and a reversible motion. But my method of control is only applicable, on account of complication of wiring and first cost, in instances where very great variation of speed and a large number of automatic speeds are required, or where the units are so large that rheostat control becomes impossible to manipulate or prohibitive in expense.

MR. GANO S. DUNN:—The figures given by Dr. Crocker, of a loss of approximately 80 per cent. of the power of the engine to drive the shafting idle are astonishing, and when the Crocker-Wheeler Electric Company first took up the question of motor driven factories this statement was challenged very generally by the authorities to whom it was made. They brought figures to show that even when three or four intermediate sets of shafting were used, the loss in the journals and belts for a given power delivered, could not aggregate such an amount; and it did seem to us at the time that there was something unexplained. Dr. Crocker's paper points out the cause, and I believe is the first paper to show it clearly. It is the fact that the tools are in actual operation for but a small portion of the total time. I do not doubt that if every tool were in operation all the time under full load, the efficiency of shafting distribution would be very much higher than the figures he gave. The figure of 75 per cent. friction loss is not a high one. We have equipped factories where it has been up to 85 per cent., and 75 per cent. can be considered as a good average condition. In the new works of the Crocker-Wheeler Company, much care is being taken to get the advantage of all points learned in our dealings with other factories, and we hope to have an illustration of the very best and most modern method of driving a shop. The wiring is to be down under the floor and to come up at each machine or group of machines where it is needed. The arrangement of circuits is such, that for occasional night or special work a very small generator can be put on and run one or two tools, and those tools may be located at any part of the factory. We hope to be able to show shortly what may be considered as standard practice for a motor system of distribution, and one which will be a precedent for some years to come.

MR. GEO. W. BLODGETT:—I had occasion a few months ago to look up the subject of driving machine tools by electrical motors, and I visited several places where that method of running machinery was in use, and it may be of interest to the members if I recite some of the facts which I learned. The Morris Safe Co., in Readville, Mass., are driving their works by electric power altogether, using a steam engine and a generator of 500 volts, I believe—80 H. P., at any rate—which drives eight motors in different parts of the shop, varying in capacity from 10 to 25 H. P., each motor being connected with a section of shafting from 30 to 50 feet long, and driving a group of tools. Their work is

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the manufacture of fire-proof safes, and they make use of machinery for doing almost the whole of the work, and all the machinery in the shops is driven by electric motors. The shop where most of the cleaning and polishing is done, by means of emery wheels, is a very difficult place to operate a motor, on account of the fine dust of the emery and steel with which the air is filled and which of necessity gets into the commutator and under the brushes to a certain extent. However, with the exception of a slight sparking, which would be considered under other circumstances a rather abnormal sparking—no difficulty is experienced—and the motor which I saw in this shop had been running for several months with no change of brushes or commutator, and only showed a reasonable amount of wear, certainly nothing dangerous. This concern formerly operated by belting and shafting alone another shop where they were running about the same number of tools and doing the same kind of work, and they estimate a saving of 20 per cent. to 25 per cent. in the amount of coal used now over what it was when they ran entirely by belting and shafting.

I visited also a concern in Worcester, Mass.—the Rice, Barton and Fales Company, manufacturers of general machinery, largely for paper mills. They use several motors of which three are on an electric crane, one for moving the crane to and fro the length of the shop, another for moving the hoist transversely, and the third for raising and lowering weights. It works with perfect satisfaction and is much more convenient, takes much less power, and there is much less weight than with a steam engine for which the crane was first designed.

The Kent and Stanley Company, of Providence, R. I., have just erected a large seven story building covering more than an acre of ground, which is operated entirely by electric motors. The machinery in the building was not all in operation when I was there, but was being fitted up, and is used principally for the manufacture of jewelry; the different floors or different parts of floors being let to manufacturing concerns which do this kind of work, some of one sort and some of another. The power was at that moment being derived from the Narragansett Electric Light Company, but dynamos and engines were being installed in the basement of the building for driving motors for the machinery on the different floors. Here the motors are usually placed on a platform suspended from the ceiling, high enough to clear the heads of people and the work which was being done on the floor, usually, I should say, at a height of eight or ten feet above the floor, and were connected by a belt to a shaft running lengthwise or crosswise of the room, and driving groups of machines. I was struck here with the saving of valuable space, and particularly with the enormous saving over what would have been required for transmitting in the old way the power from the basement to the top of the seven story building and around in differ-

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ent places on the several floors of the building. The arrangement of shafting and pulleys to do that work would have been extremely complicated.

I have myself recently installed an electric motor for driving a transfer table in some railroad shops, the table being a little over 65 feet long, weighing 78,000 lbs., and adapted to transfer a locomotive which weighs 204,000 lbs., making the total weight of the table and its heaviest load more than 280,000 lbs. It runs upon two rails in a pit, and the power is applied by a shaft running the length of the table and connected to wheels at each end which run upon these rails. In the first starting of the table, owing to a fault in its construction, a part of the iron work rested upon the rails, and the weight did not come upon the wheels but upon these iron pieces which supported a part of the weight of the table. A 25 H. P. nominal "G. E. 800" motor was used, and we put on at a voltage of 450, more than 100 amperes without starting the table at first, although we were able to slip the wheels on the rails without moving the table until the difficulty was found and remedied. Now it takes 15 to 25 amperes at 450 volts to run the table, and it works much more smoothly than it formerly did. It has only been in operation a few weeks and will doubtless act better when it has been a longer time in service.

Mr. C. R. Van Trump:—The engineer who has to do with generating and furnishing motor power is, indeed, indebted for the figures that are given in this able paper. It gives us a clue that we certainly have not had before, and brings out some very important points. Electricity from a central station certainly appears expensive to the ordinary manufacturer who intends to run his shop with it. It is expensive because it all comes in a lump, in one bill, where in the case of steam power or other motive power, he has his labor and his coal and other expenses, repairs, that come in one by one, and he does not know how much his power does cost him. In the case of electricity, however, he gets his bill once a month from the central station, and it seems very large indeed. I have had some experience quite lately in this very line, and will mention one case only, of a small printing shop that was complaining very strenuously about the cost of electric power, and, in testing the matter out, we found that it cost them about 15 cents an hour to run the shop with nothing on. At 10 cents per K. W. hour his largest press consumed about nine cents an hour, and it was run very little indeed. His next largest press cost him about five cents an hour to run, and the others about two, of which he had three. He did not run more than two or three presses at a time, and never the large one when he ran the others, so that his frictional losses were certainly quite extensive to him.

Mr. Harry Alexander:—Having recently had occasion to demonstrate some of the facts mentioned in this valuable paper it might be well to speak of the circumstances. In fact just be-

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fore I left we made some tests in a certain business house in New York that runs machines for manufacturing purposes, having about 25 H. P. (I believe a) Whitehall Corliss engine to do the work; we were trying to displace this engine by a motor. They did not feel free to do so until we made a test. The card of the engine taken at the time by the engineer of the company, showed 22 H. P. with 179 lbs. of coal. The steam was carried about 80 feet. We took a 20 K. W. dynamo, coupled it to exactly the same shafting, the conditions being exactly alike, the coal being shoveled directly from a scale. The figures showed, with the same amount of machines going, the same work being done, 140 amperes, which is about 20 H. P., counting about 800 watts to the horse-power, at 92 per cent. efficiency. The saving of coal at that time was 100 lbs. for the same period, the coal being 80 lbs. against 179 lbs., the card on the engine showing 22 H. P., while, as I said, at 800 watts per H. P. the motor showed about 20. After that test was made, we installed a motor in the laundry down-stairs, a five H. P. motor, running, I believe, ten hours. The motor, when all the ironers were at work, consumed an average of 34 amperes. At that time we decided to run the ironers in pairs, as they usually were run, but instead of transmitting the power through a counter-shaft, decided to couple a one H. P. motor to each pair of ironers. After that was done, although temporarily, the counter-shaft not being removed and the motor merely placed between the two ironers, our current consumption for exactly the same work done was a little less than 20 amperes, or four amperes per machine, there being five one H. P. motors to operate each pair of ironers; and in view of these circumstances I should say that this alone showed the house the advantages over the transmission of power through belting. I have not quite concluded the test, as things were not in shape at the time I left for me to give any further exact figures, but under the circumstances, especially in the laundry, I dare say that the figures will show that the independent motor under certain conditions is very efficient indeed. And as to the 35 H. P. motor that we installed up-stairs, on the strength of this test, we have decided, instead of the one 25 H. P. motor, to run the floor above, which is principally operated by an engine now, to lay it out in four wings, operating each wing by an independent motor of about five to seven or seven and one-half horse-power each.

Dr. S. S. Wheeler:—A large portion of the electric factory equipments are decided upon, because of the flexibility and convenience of the system, and therefore I think that this feature deserves a little more emphasis than it has received in Dr. Crocker's paper. There are very few electric power plants put into factories simply because it is the ideal or the most perfect system. I think the prevailing rule is that the manufacturer waits until he finds that he can go no further in the development of his factory with his shafting, and is forced into some

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other means of securing power. The use of wires of course enables the manufacturer to carry the power to remote points on his property much more easily and quickly than he could carry it by shafting, and that is particularly true when any alterations or additions are to be made. I know of several instances on hand at present, where the owners of factories have decided to go to the small increased expense of electric power, because they wanted to tear down a part of their buildings, and by adopting an electric system they could continue the power in the remote parts that were not being torn down, while the intervening buildings were removed. By the use of electric service they could string their wires across the spaces and fill the factory up until they came to the limit of their engine capacity. And then we have been called in to introduce electric power in place of shafting as a means of reducing the load on the engine, so they could continue their manufacturing. In other cases we have put in electrically driven machinery, so that part of a factory might be driven from a city circuit, while they were rebuilding the engine room. In our own work we had a large 50-inch lathe in a building which was completely destroyed by fire. That lathe was in operation within two or three days after the fire, right out in a field, driven by a small pole line from the engine room, and with a small canvas tent over it to keep the rain and brick dust off while the re-building was going on. That lathe has, owing to the pressure of our work, been in continuous use day and night from two or three days after the fire until now, when the new buildings are completed over it. That, of course, would not have been possible if it had been a shaft driven tool, but as an electric tool we could keep it running all the time. In the same way we have been able to shift other tools around on roller trucks and in all sorts of ways to various parts of the shop, and put wooden sheds over them, and keep them going, and when the building came to the point where they stood, we would take them up and roll them along 20 or 30 feet further, get them out of the way and keep them running.

Capt. Wm. Brophy:—In his conclusions, the author of this paper has omitted one very important factor in favor of the electric motor. Every man in business finds it necessary to insure his property against loss by fire. We all know that the small boilers and small engines placed in basements or in attics have been a fruitful source of fire. If the fire starts in the basement, it spreads rapidly through the upper portions of the building. If the boiler and engine is located in the attic, or upper story, the entire building and the goods contained therein are injured by water, entailing a very heavy loss on insurance companies. I regret to say that there are some insurance associations still so benighted that they cannot appreciate this fact, but most of them do All of them will yet emerge from the wilderness and realize that the electric motor is a great benefactor to them in their

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business. There have been a few cases of fire, as I must admit, that have been traced to electric motors, but it is due to the carelessness of those who install them, or of those who have them in charge. But there is no reason why an electric motor should be more hazardous as a fire risk than a refrigerator.

MR. OBERLIN SMITH:—I read yesterday in a local paper here that Niagara Falls was the "electric city," but probably not being fully developed, they have not yet got electric bells into my room, nor any other electric waking-up arrangement. Some of my most highly charged electric friends here stored me so fully, a good while after midnight, with valuable high-potential knowledge, that I didn't get switched on to the breakfast circuit very early this morning, and so I didn't hear all of this valuable paper. I cannot talk about it as clearly as I would like to, through thus being a little late, but next time we come, the city will doubtless have become more electric, and all these things will have adjusted themselves.

From the point of view of a mechanical engineer more especially, I want to say that with those of us who have thought most and seen most of the subject, there is no question any longer but that we want to drive our tools with motors. I do not think we need any more discuss whether we shall or shall not, as we did perhaps a year or two years ago. We were then feeling our way. Following the wonderfully rapid strides in electrical development, we have now gotten to a place where we need not ask the main question. We want to use them as a matter of course. It is only a question of time when they will be in all our machine-shops and in all other mills, even cotton mills and such places where the power required is very constant, where really we do not need them as badly as we do in the machine-shops and other places where the power is extremely inconstant. What we want to discuss, and what we are discussing here, is merely methods and kinds of apparatus. My experience has not been as great yet as I would wish, although that is a matter the future can remedy. As far as it goes, it has been chiefly with punching and cutting presses and I can say that, so far, the behavior of motors under such circumstances has been admirable; and we cannot expect a motor to act as well in intermittently acting machines of this kind, as we can with a lathe, or even a planer. Drill-presses, lathes and milling machines, where a constant torque is usually required, at any rate for a few minutes at a time, are much easier on a motor, than is a press where the power required for running a loose flywheel for a while is almost nothing, and where the torque is then increased instantly for only a fraction of a second, perhaps 1,000 or even 5,000 per cent., then going right down again. All this is well taken care of, however, with a heavy flywheel and with the peculiar adaptation of a motor for such work. In running press flywheels light, a little object lesson has, I think, been gained in calling the attention of people who use

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such machines to the considerable power that is being wasted in ordinary shafting journals. Most of us would hardly realize it till we tried it, and probably with nothing but the old fashioned dynamometer we might never have taken the trouble to bother with a flywheel running loose on a stationary shaft. I was somewhat surprised myself to see that from one-half to one horse-power was required for the ordinary press flywheel, medium size, weighing, say, from six to twelve hundred, or something of that sort. The journal friction in such cases has a coefficient of perhaps 15 or 20 per cent., with cast-iron running or forged steel, under ordinary conditions. When, therefore, you watch an ammeter and see that it registers 700 or 800 watts with a mere loose flywheel running around, you can very well realize what the waste of power must be with a mass of shafting and counter-shafting and idlers of all kinds, and tight belts bending over the shafts out of line. This increased facility of observation is an incidental advantage which the motor will be to us, and makes an ammeter a very pretty thing from which to read the power used at any moment by the machine being driven. We then have a simple and glorified form of dynamometer, so to speak, such as we never would otherwise have used.

A motor is sometimes a good thing for such work as driving presses in time of breakdowns. I had recently an experience that showed the advantage of such driving instead of having a mass of transmission machinery attached to the press with a tight belt. I was testing a press that would give about 50 tons pressure for punching iron with holes one inch in diameter. A number of pieces were brought from the smith-shop, of different thicknesses, and everything worked all right until one was put in which looked like rusty iron, and which the blacksmith sent in from the iron pile, assuring us it was a "piece of iron," like the rest, but which happened to be unannealed tool-steel. It was far beyond the capacity of the press to punch such a piece of metal, and something had to give. The die was mounted upon a cheap "bolster," which very properly cracked so that the stress did not break the machine itself; but the motor behaved admirably. The fuse went off with a "fourth-of-July" sizz, and the motor slackened itself right down so that everything stood still without any damage at all; whereas if we had been connected with the whole plant of an ordinary machine shop, I don't know what would have happened.

A little point mentioned by Mr. Dunn is, I think, a valuable one in equipping motors, where he spoke of the wires all coming from underneath. In the factory he referred to, I believe formerly a good many of them came from overhead, and that was my one criticism of what was otherwise an admirable system. One of the great advantages we have in driving individual machines with motors is the getting an entirely clear room, and I never could see any possible objection to bringing the wires from under

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the floor. We then get the ideal condition for a shop. Aside from the advantage of more unobstructed light in general, and the chance for using sky-lights if we have them, and the light from our windows, by getting rid of all overhead machinery and rigging, we have one very important thing that has not been enough dwelt upon, and that is head-room for our future electric cranes. I do not mean the crane we now build. The crane industry has gone only a little way, although there has been a good deal of it; but I do not think any of us rightly conceive of the great convenience and rapidity of work that is coming from the handling of our small loads by this means, with the light overhead crane that is yet to come, driven by electricity, running everywhere, raising anywhere from 50 pounds to a ton. When we get this ideal system of driving—one that is becoming real, too, especially in the shop mentioned by Dr. Wheeler and Mr. Dunn, and some other shops, with everything connected from the floor and nothing overhead, we shall have our present type of ordinary traveling cranes over our heavier conventional tools, over our lathes, planers and drills. Now we limit them to erecting-floor use, and do not think of putting them over our common lathes and planers. Each of these now require the work to be lifted in by hand or by some special crane of its own, generally a hand crane. We can also have little electric cranes in special cases running from certain tools over to other tools and individual cranes upon as many as we please. Of course those cranes will be cheapened as the system develops, and there will be an enormous saving in the handling of work. Now, for anything but very light work which the men can pick up and put right in the machine, there is a considerable waste of time putting work in and out of machines—more than any one would realize, and often amounting to more than that required for the actual cutting. All this is going to be one of the direct results of the clear head-room brought about by the use of motors.

The system that has been talked about a good deal of grouping three or four or five machines to little pieces of shafting on the wall or ceiling, is a good one in certain cases, and during this tentative period no doubt has its proper place; but I do not think it has come to last, because we get the disadvantages to some extent of the old shafting system. As motors become better and cheaper, as they will, we can afford to have one for every tool and get the full advantage of individual driving. The problem talked much about until quite recently has been whether we should put in motors at all, because we did not know whether they were going to take more power or not. As remarked in the paper, that is a point of very little importance, compared with the total expenses of the shop. It doesn't matter if it is five or ten or twenty per cent., considering the great advantages we are going to get in all these other ways.

One feature that has been touched on might perhaps be

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brought out a little more in detail, the balancing up of all power so that only the average need be represented. Taking the extreme case of a press, which is more intermittent in its action than almost any other machine perhaps. It stands quietly waiting for the work to be put in and adjusted, then is clutched in gear and the ram allowed to come down idly till it strikes the work, which is a comparatively long time; then the punch goes through the work in a very short time, then a rather long time is occupied for the punch to come up through the work, and for the ram rising the rest of the way and the machine coming to rest, removing the work and all that. Here we have a maximum of power exerted during an extremely small percentage of the time. The chances are that with a number of presses standing in a shop, the rams would never all happen to be doing their hardest work at the same instant. We therefore have our power averaged up pretty evenly most of the time. Not so, however, with shafting systems which must be prepared for maximum stresses.

The point mentioned by Dr. Wheeler, of arranging shops for growing afterward, is an important one. Even where, with good foresight, the shafting of a shop has been so planned, and the building so planned that they can be lengthened out indefinitely, or where it is arranged for other future lines, alongside and parallel to existing lines of shafting, a difficulty arises on account of the limited diameter of the shafts and pulleys and width of belts which could hardly be made high enough at first for a growth of 50 per cent. next year and another 50 per cent. the next, and so on. Now electrical machinery gives us a great flexibility for increase, which is a most important consideration.

Without going through the points of the paper carefully, but glancing (in reverse order) at the summing up thereof, we find that: The speed regulation Dr. Crocker speaks of is an important matter and very easily managed with an electric motor. There is an enormous waste of time in lathes, cutting off machines, etc., especially where the feeds are running radially, starting on a large diameter and feeding to the center. This can all be arranged by electricity so as to get a gradual increase of speed. The truth is that with the average lathe, which is the most important tool we have in our shops, the man running it is too lazy or too ignorant to change his speed as he might in making cuts radially across the face of the work. The result is he gets his speed four times or more too slow as he gets towards the center. The same is true in turning different diameters on a shaft where there are a number of diameters. It is usually too much trouble to change his belt, especially with a high ceiling. Shifting belts makes dirty and sometimes cut fingers, which he avoids if possible. The electric motor, with a little switch, gives one perfect control of all this.

Beside the actual high speed and the speed regulation which we get from the motor, in many cases just where and when it is

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wanted, there is also the moral effect of having everything going lively. An electric shop is not going to be an old-fashioned shop, with everything crawling and creeping and waiting for something. The spirit of electricity is in the air and all this undoubtedly has a mental effect on the men and is going to spur everything up and make things run faster.

The motor system's flexibility, allowing the moving about of the tools at will, is a very good point of Dr. Crocker's. The capability of stopping a part of a shop and running the rest is also an important advantage—as, *e. g.*, during strikes, etc. Other occasions may require running part of the shop at night, instead of the whole of it, as in making overtime. In general, great benefits result from having complete control of all the different units of the shop, instead of having to link and fasten all together like a lot of convicts chained together by the legs. Neither men nor machines can work as well that way as they can with more individual action. The actual saving of power has been touched upon already, and I am inclined to believe there will in the end be a saving, in spite of the different transformations of energy between prime-mover and tool.

Regarding some other points not included in the summing up of the paper. One of these was mentioned by my friend here just now, (Capt. Brophy) namely, fire safety. Another one that has not been mentioned, I believe, is that when we introduce a current through a shop, either from our own local generator or from outside, produced from some big and especially economical cataract or steam engine, we have something that we want for other things beside power. We want it now for lighting, and also perhaps for welding, soldering, etc. We shall want it in future for heating, which I believe is destined to a great extent to be by electrical methods, although we know it costs too much just now. It has, however, so many incidental advantages that such heating is very likely one of the coming things. At any rate 'tis good to have our power in shape for a variety of functions instead of only for one purpose as we get it in our old belts and shafts.

The moral effect of an electric shop I have already referred to, and this is augmented by the greater amount of God's daylight you can get in connection with the gaining of the clear head-room before mentioned. This daylight is better not only by getting all our "rigging" away from overhead which now obstructs the greater part of the light, but because we can conveniently whitewash our shops or otherwise make them some light color which we cannot or do not do now. The average shop is so filled with shafting, hangers and belts that the overhead parts are sometimes whitewashed once in five years only, but sometimes not once in ten, because it is difficult to get all around it. The general healthfulness and cleanliness of this new era shop, avoiding the dust and surplus oil and old grease that comes from shafting, etc., thus enabling the shop to be kept looking more like a ball room,

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comparatively speaking, is also going to help the men to do more work and going to pile up this moral effect I have spoken of.

We come now to the first item in Dr. Crocker's summing up, the cost of an electric plant. I fancy that the things I have been saying will be popular with electric men, because they want to see electricity go ahead, as do I also, from the standpoint of a mechanical engineer, but I am afraid I shall be unpopular if I say anything about motors costing too much. I tried it once or twice at various engineering meetings, and there was immediately a laugh or a weep, or something of the sort,—as much as to say that we poor ignorant mechanical men did not know anything about *that;* we had no idea of the enormous cost of these pieces of iron and copper and string put together, and we knew nothing about the way to put them together. There was a great mystery connected with electric motors and generators that we could not fathom, only by an extremely arduous course of electrical engineering. Whenever we would touch upon that ground, we were warned to keep quiet. But unless machine-shop men and cotton-mill men are prepared to pay the present price for motors, there is no use in talking electric power, and therefore I am going to say what I can say now better than I did before, because we are coming nearer to the time of cheap electric motors. They are cheaper now than they were. I find no fault with past and current prices, because they are perfectly legitimate, and are based in some degree upon the enormous amount of experimentation that has been necessary as a part of that dozen years of development which is one of the marvelous things in the history of this century. These splendid young men who mostly form our INSTITUTE OF ELECTRICAL ENGINEERS are going to continue that development. The old gray-heads hardly seem to "be in it" at all, if I may use such an expression. But this great industry that has come up like magic has cost enormously for the experimenting, for the litigation, and for the selling of a new product. All this has naturally gone into the cost of the motors and generators, besides the actual cost of making. The extra burden is, however, gradually disappearing, as things are getting down nearer to a standard, and the patient experimentation has given us these splendid motors with 90 to 95 per cent. efficiency—we do not need go much further in that line. But when we come to the mere mechanical construction of them, we all know that the material does not amount to a very large factor of the selling price. The labor is the problem.

The important economic question upon which mechanical engineers and electrical engineers should study together for the next few years is, when we have arrived at what we may consider the standard type of motor, how to make it cheap in regard to labor. This cheapness will come in the course of the evolution that has shown itself in manufacturing such things as sewing machines, and pistols, and bicycles, and typewriters. Such me-

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thods are coming with the electric motor, and we shall learn to use more automatic machinery as well as to design the motors to suit it. This is largely a problem for the mechanical people, but they will doubtless rise to the occasion. This country is too brilliant in inventing tools and methods of work to ignore such a chance. Of course, important elements in making motors cheap are not only special tools, but the running through of large quantities in a "batch." This, I admit, is a difficult matter now. Factory men cannot at present prices buy enough motors to warrant electrical men making them up in large quantities; nor can these makers afford the equipment for cheapening until the demand increases vastly. Just as soon as we can make them in large enough quantities, 10,000 or 20,000 lots, all exactly alike, there is no question but that they can be made very much cheaper than now. All this will work itself out in time. The new era is coming, and just as soon as they do get cheap, we shall all be surprised at the immense number of them that will be used. I feel perfectly sure, as far as I am concerned, that they are going to be used as individual motors on every separate machine in very many cases. Not in all cases, but in a majority, probably.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 26th, 1895 President Duncan in the Chair.

SOME FEATURES OF ALTERNATING CURRENT SYSTEMS.

BY CHAS. PROTEUS STEINMETZ.

In the following I intend to review some of the work done in the last few years in exploring the actions and reactions of alternating currents. I shall endeavor to avoid as far as possible the use of mathematics, but I must beg you to believe that all the statements made are paralleled by exact mathematical calculations which have been partly published already, or which will be published in due time, but which if introduced in the present paper, would extend beyond the scope intended.

The practical applications of the modern alternating current system date from the introduction of the alternating current transformer. The possibility of transforming the voltage, and thus to use high voltage in the line and low voltage in the consumer circuit, gave the alternating current system a superiority not shared by the continuous current system, and thereby put the latter out of competition wherever great distance had to be traversed. A further advantage has been added in the last few years only, by the superiority of the alternating current motor over the continuous current motor, due to its greater reliability, better speed regulation and ability to stand overloads which made it preferable at least for high grade work.

It was not so in the beginning of the period of alternating current distribution. For a long time the system labored under the disadvantage of not being able to supply motive power, being available for lighting only. The inability to operate motors was the more serious as the alternating current system by its very nature is specially suited for long-distance transmission. In long-

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distance transmission, however, the object aimed at is in general, at least partly, mechanical power. Thus the alternating current motor became the problem of those times. The alternating current generator, when running at synchronism in parallel with other generators, will keep on revolving even if the driving power is removed, and will operate as a "synchronous motor" keeping absolutely in step with the generator. Such synchronous motors are quite extensively used now, especially for large units. They have, however, the disadvantage that they are not self-starting, but must be brought up to synchronism before operating as reversed generators. Thus, either external starting devices had to be used or the synchronous motor made what is called "self-starting;" that is built so as to operate in starting and running below synchronism as a synchronous, or induction motor, or that variety of the latter which is called the "reaction motor." Thus, the

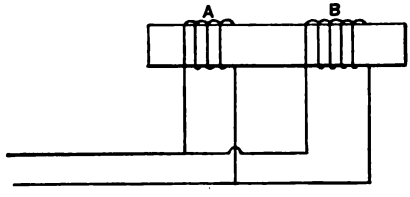

FIG. 1.

reversibility of the alternating current generator did not bring a complete the solution of the motor problem.

The solution of the alternating current motor problem had to be expected, either by the adaption of the continuous current motor to alternating current circuits, or by the discovery of an entirely new principle. The introduction of polyphase systems appeared to give the solution in the polyphase induction motor.

If by a system of E. M. F.'s displaced in phase from each other, currents displaced in phase are sent through the field circuits of a motor with short-circuited armature, rotation of the latter is produced.

This motor necessitates the use of polyphase systems, that is, systems comprising several circuits differing from each other in phase of their E. M. F.'s and currents. Such polyphase systems

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require the subdivision of the single phase load, as lights, into and between several circuits, and require an approximately equal division to avoid on the one hand overloading of an individual circuit of a generator, while the generator as a whole is not yet fully loaded, and on the other hand to avoid the feature of "unbalancing" noticed in such systems. Since the different circuits of the polyphase system originate in the same generator, and the field excitation of an alternator has to be varied with the load, it is obvious that two circuits issuing from the same generator when loaded differently, will require different field excitations and thus at the same field excitations will show different voltages, the lesser loaded circuit, a higher voltage. The drop of voltage in the transmission and distribution lines being larger in the higher

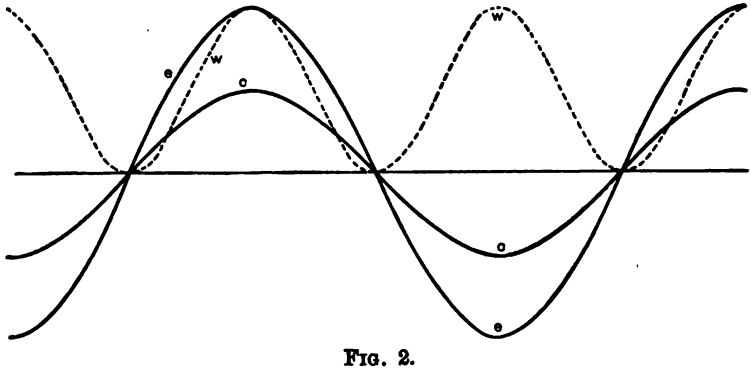

FIG. 2.

loaded circuit, will decrease the voltage of this circuit still more, and thus increase the unbalancing effect. Hence, even if the variation or potential at the generator terminals due to difference of load of the different phases should be small, it will be increased by the lines.

However, aside from this difficulty, the experience of the last few years seems to show that the complication of subdividing the circuits in the polyphase system is sufficient in most cases to exclude its use, and thus, comparatively little use has been made of the polyphase systems for light and power distribution. It has been different with long-distance transmission of large units, and power distribution, where polyphase systems have established themselves quite extensively.

Hence, the polyphase system did not completely solve the problem of alternating current light and power distribution,

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and in returning to the single phase system, attempts were made to derive from the single phase system by "splitting of phase," a polyphase system for the operation of motors.

The futility of all attempts to derive a polyphase system from a single phase system, I have previously shown[1].

It is possible in a single phase system to resolve the E. M. F.'s into components in quadrature with each other or in any other phase relation. The insertion of a reactive coil into a lamp circuit produces two E. M. F.'s approximately in quadrature with each other and differing in phase with the main E. M. F., and by their combination any other phase differences can easily be produced. A condenser in series in the circuit, or an electrolytic cell will give phase displacement of E. M. F. also. But whenever E. M. F.'s displaced in phase are produced in this way, the cur-

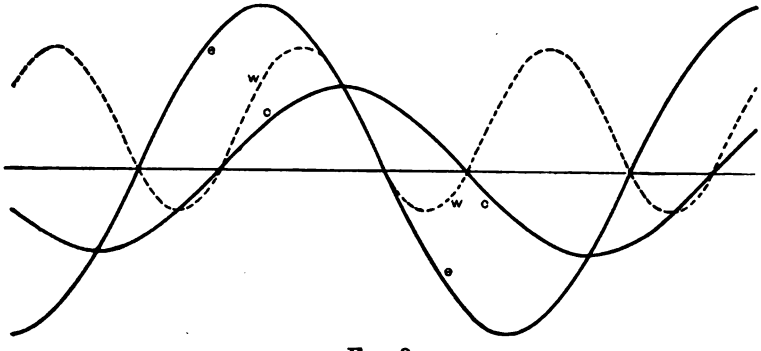

FIG. 3.

rents are in phase with each other or are insignificant.

Inversely, differences of phase of current can be produced in the single phase circuit. The current is an open magnetic circuit transformer at open secondary circuit, and the current in a transformer under full load, are practically in quadrature. Or still more, if on the same iron core two coils are wound and connected in parallel as shown in Fig. 1, the two currents in these coils can by changing the relative number of turns be made to have any phase difference from zero to 180°, but the E. M. F.'s are in phase. All attempts to use such phase differences produced in the single phase circuit for the operation of polyphase motors signally failed. While it is possible to operate motors in

1. TRANSACTIONS, 1892, vol. ix, p. 91.

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this way, and this is being done to a certain extent, the current required is far in excess of the torque produced thereby. Such circuits of displaced phase lose their phase displacement as soon as work is required from them. The cause is that phase displacement of current, and phase displacement of E. M. F. cannot be produced simultaneously in a single phase circuit. This is a consequence of the law of conservation of energy.

In a continuous current circuit, current, E. M. F., and thus the power as their product are constant.

In a single phase alternating current circuit, the E. M. F. alternates, passing through zero twice per period. The current produced thereby alternates also, passing through zero either at the same moment with the E. M. F., in a non-inductive circuit, or at a different moment.

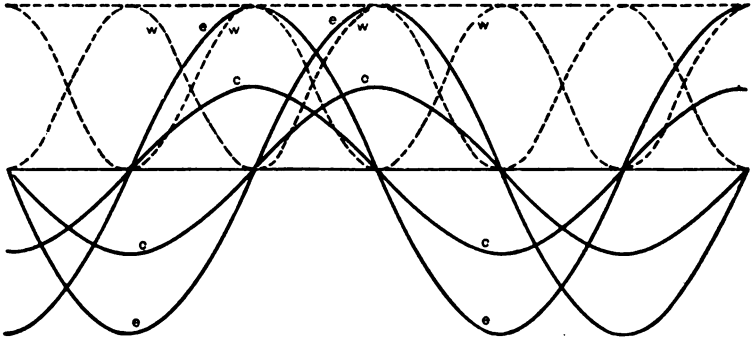

FIG. 4.

Thus the power of the alternating circuit is fluctuating and varies twice per period, that is with the double frequency of the E. M. F. or the current, between a maximum value and zero in the non-inductive circuit, between a maximum value and a negative maximum value in a circuit with phase displacement between current and E. M. F., in the latter case, passing twice through zero per half wave, as shown in the diagram Figs. 2 and 3, where the E. M. F. is represented by the drawn line *e*, the current by the drawn line *c*, and the power by the dotted line *w*.

In the polyphase system, as a quarter phase with two E. M. F.'s in quadrature producing two currents in quadrature, as in Figs. 4 and 5, or in a three phase system with three E. M. F.'s producing three currents, as in Figs. 6 and 7, the energy wave of each phase is fluctuating as in the single phase system. The sum of

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all the energy waves, however, or the total flow of energy is constant.

From the law of conservation of energy, it follows thus, that a change from a single phase to a polyphase circuit or inversely, is possible only by means of apparatus able to store energy, and that the total amount of energy between the mean and maximum value in the single phase circuit must be stored and returned during the time the single phase wave is below the mean.

Means to store the energy are, electro-magnetism, electro-static charge, electro-chemical force and mechanical motion. Electro-magnetic and electro-static storage are in most cases excluded by low energy efficiency and especially low weight efficiency and inconvenience. Electro-chemical storage shows a very low efficiency, and the only efficient way of storing energy ap-

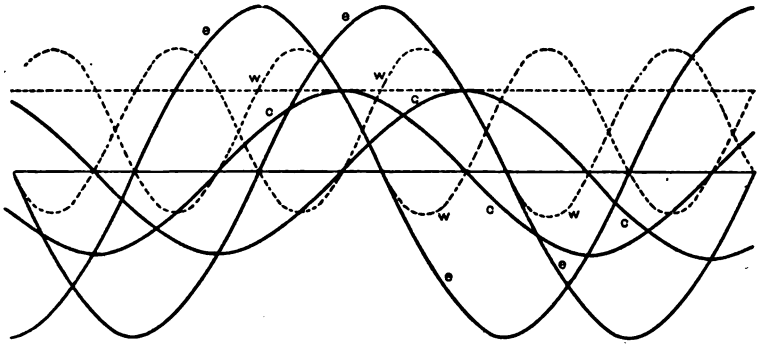

FIG. 5.

pears to be mechanical momentum. This offers a high weight efficiency also, but is for most cases excluded by the complication due to revolving machinery.

Excluding storage of energy, we see that the *nature of the flow of energy constitutes an essential feature of an alternating current system.*

The phase relation does not represent an essential feature, since, as seen, starting from a single phase generator we can get currents of different phase relation and E. M. F.'s of different phases, but if the currents are displaced in phase, the E. M. F.'s are in phase and inversely, so as to preserve the nature of the energy flow. Again, starting with a quarter phase generator we can transform by stationary transformers without storage of energy, that is at full efficiency, to

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three phase and back again to quarter phase or five phase or any other symmetrical or unsymmetrical phase relation. In all these transformations, however, the nature of the energy flow remains constant. Hence the best classification of the alternating current system is by this feature, the classification by the number of phases having become meaningless with the possibility of transformation from one polyphase system to any other. Thus we shall call an alternating current system of constant flow of energy, a balanced system; an alternating current system in which the flow of energy pulsates between a maximum and a minimum, a system of balance factor x, where x is the ratio of the minimum value to the mean value or energy flow. Hence the balanced

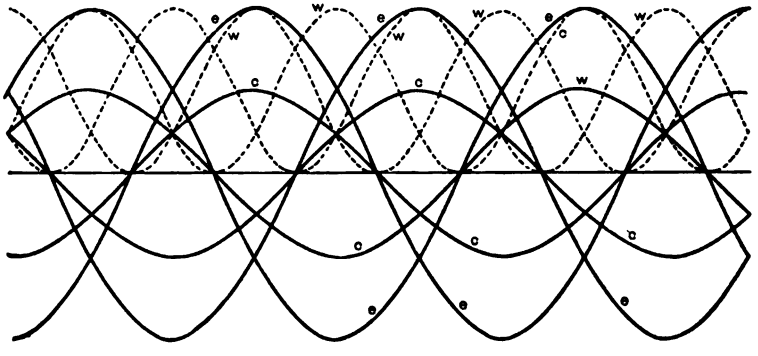

FIG. 6.

polyphase system has the balance factor, one; the single phase system the balance factor, zero.

I may add here that the names "polyphase" and "single phase" are really wrong, and the latter name meaningless, since "phase" becomes a meaning only as "difference of phase."

The systems are characterized correctly, not by the existence of one or several phases, but by the existence of one or several waves of energy, or cycles, and for this reason I rather prefer the denotation "polycyclic" for a system of many waves of energy, "monocyclic" for a system with one wave of energy. Hence:

The *monocyclic system* is an alternating current system of *balance factor zero.*

The *balanced polycyclic system* has the *balance factor one.*

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The three phase or quarter phase system with equal load on all branches has the balance factor one.

A three phase system with two branches loaded and one unloaded has the balance factor .5.

A three phase system with one branch loaded and two unloaded has the balance factor zero.

A quarter phase system with one branch loaded and the other unloaded has the balance factor zero.

Still from another point of view, we are driven to recognize the importance of the flow of energy as characteristic in alternating current circuits.

In a continuous current circuit, the direction of transmission, or direction from the generator to the consumer circuit, is in the direction of decreasing voltage.

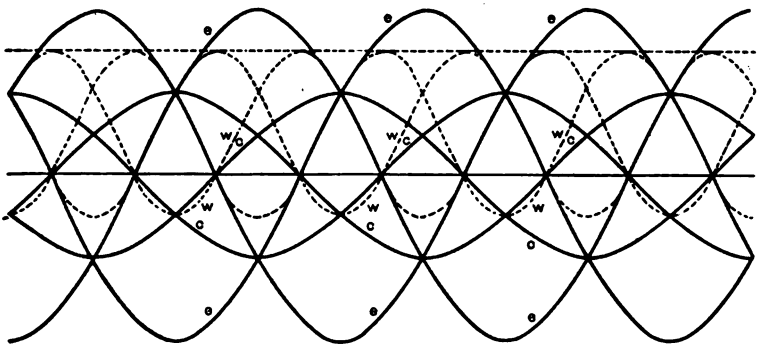

FIG. 7.

In an alternating current circuit, the voltage at the consumer terminals of the line may be higher than at the generator terminals of the line, and the power be transmitted from lower to higher voltage. This is the case in a line of noticeable inductance feeding into a circuit with leading current. Inversely the current received from the line at the consumer terminals may be larger than the current issuing from the generator into the line. This is the case with a line of noticeable capacity feeding into a circuit with lagging current. These features are made use of now in long-distance transmissions for controlling the potential and the current flow in line and receiver circuit.

Hence, the direction of transmission in an alternating current circuit is not necessarily the direction of decreasing voltage or de-

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creasing current, but it is the direction of decreasing energy flow. That is, attaching a wattmeter to two points of the line, the wattmeter nearer the generator will always give a higher reading than that farther away from the generator.

An apparent disadvantage of this definition by the nature of the energy flow, is that with a change of the distribution of load, the nature of the system, or at least its balance factor varies. But in this case the characteristic feature of the system in reality changes. It is obvious, for instance, that if one branch of a three phase generator only is loaded, the circuit, as well as the gener-

FIG. 8.

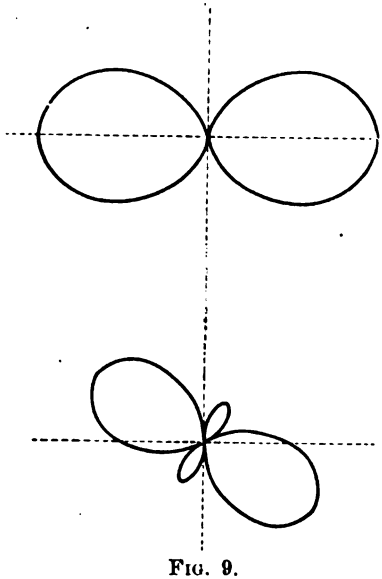

FIG. 9.

ator acts in every way as single phase and is indeed single phase, and the remaining generator circuit merely dead wire.

The total flow of power in an alternating current system can be represented also by a polar diagram, with the instantaneous values of power as radii vectors, and the angle corresponding to time as amplitude, one complete period being represented by a complete revolution or 360°. This gives a power diagram of the alternating current system corresponding to the compound indicator diagram of the steam engine.

In a single phase system of E. M. F.,

$$e = E \sin \varphi,$$

and current:

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$$c = C \sin (\varphi - \tilde{\omega});$$

the power is:

$$w = e\,c = E\,C \sin \varphi \sin (\varphi - \tilde{\omega})$$
$$= {}^1/_2\, E\,C \{\cos \tilde{\omega} - \cos (2\,\varphi - \tilde{\omega})\},$$

and the average power:

$$W = {}^1/_2\, E\,C \cos \tilde{\omega}.$$

In polar coordinates, the power diagram of the two circuits shown in Figs. 2 and 3 is represented by Figs. 8 and 9; Fig. 8 representing a non-inductive circuit, Fig. 9 a circuit with 60° lag.

In a system comprising several E. M. F.'s and currents, in every

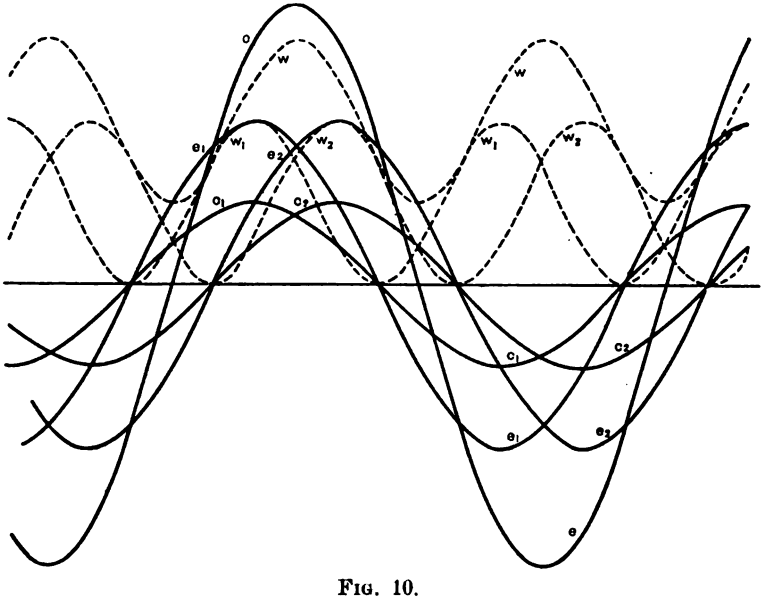

FIG. 10.

part of the circuit the power can be represented in the form:

$$w_1 = {}^1/_2\, E_1\, C_1 \{\cos \tilde{\omega}_1 - \cos (2\,\varphi - \tilde{\omega}_1)\},$$

and, adding the power values of all the circuits, we get for the total power of the system an expression of the form:

$$w = \Sigma\, w_1 = A + B \cos (2\,\varphi - \vartheta),$$

with the average value of power:

$$W = A,$$

the maximum value of power:

$$W_1 = A + B,$$

the minimum value of power:

$$W_2 = A - B.$$

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The maximum and the minimum values of power take place at right angles with each other, or in quadrature, and we can thus speak of the two axes of the power diagram, the large axis W_1, and the small axis W_2.

The balance factor is:

$$K = \frac{A - B}{A}.$$

The balanced polycyclic system gives:

$$B = 0,$$

or a constant flow of power, which would be represented by a circle. The nature of the curves representing the power characteristic is found by reduction to rectangular coordinates.

In the equation:

$$w = A + B \cos (2 \varphi - \vartheta),$$

substitute:

$$w = \sqrt{x^2 + y^2}$$

$$\tan (\varphi - \frac{\vartheta}{2}) = \frac{y}{x},$$

it is:

$$\sqrt{x^2 + y^2} = A + 2 B \frac{x^2 - y^2}{x^2 + y^2},$$

or:

$$(x^2 + y^2)^3 = \{x^2 (A + 2 B) + y^2 (A - 2 B)\}^2,$$

a sextic equation, with the center as quadruple point.

Substituting:

$$A = W = \text{average power},$$

$$\frac{A - B}{A} = \varkappa = \text{balance factor},$$

gives:

$$(x^2 = y^2)^3 = W^2 \{x^2 (3 - 2 \varkappa) + y^2 (2 \varkappa - 1)\}^2.$$

In a single-phase circuit, it is:

$$\varkappa = O,$$

$$(x^2 = y^2)^3 = W^2 (3 x^2 - y^2)^2.$$

In a balanced polycyclic circuit:

$$\varkappa = 1,$$

$$x^2 + y^2 = W^2.$$

In a polycyclic system of balance factor:

$$\varkappa = .5,$$

$$(x^2 + y^2)^3 = 4 x^4 W^2.$$

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As an instance of a polycylic system of a balance factor less than unity, the "Inverted Three-phase System" ("polyphase monocyclic") may be discussed.

If in a three-phase system, two transformers are connected with their primaries into two branches of the system, and one of the secondaries is reversed with regard to the other, the two secondary E. M. F.'s $\overline{ac} = e_1$ and $\overline{cb} = e_2$ differ in phase by 60°, while the corresponding primary E. M. F.'s $\overline{AC}$ and $\overline{CB}$ differ by 120°.

The secondary system produced hereby has features in common with the three-phase as well as with the Edison three-wire system, and forms a connecting link between both systems. It has the balance factor: $x = .5$. The E. M. F. between the outside wires $a\ b$ is $\sqrt{3}$ times the E. M. F. per circuit, $\overline{ac}$ and $\overline{cb}$. With both branches $\overline{ac}$ and $\overline{cb}$ equally loaded, the currents in all three lines a, b, c are equal, and their sum is zero, exactly as in a three-phase system.

If the load of one branch, say $\overline{cb}$, is reduced from equality with the load on $\overline{ac}$, down to zero, the current in b decreases constantly, while the current in the common line c first decreases, reaches a minimum, and then increases again, reaching at no-load on $\overline{cb}$ the same value as at full load on $\overline{cb}$. That is, if the load on one branch is thrown off, the current in the common wire remains the same in intensity, but shifts in phase by 60°.

In Fig. 10, the three E. M. F.'s $\overline{ac}$, $\overline{cb}$ and $\overline{ab}$ are shown as e_1, e_2, e, the three currents in a, b, c as c_1, c_2, c, in drawn lines, while the watt-curves of the two branches $\overline{ac}$ and $\overline{cb}$ are shown as w_1 and w_2, and the total watts of the system as w, in dotted lines for a non-inductive circuit.

Fig. 12 gives the power diagram of the system in polar co-ordinates.

With an inductive circuit of an angle of lag of 60°, the balance factor of the system becomes $x = 0$, and the flow of power single-phase, as shown in Fig. 11 and 13.

In an alternating current system there is a certain tendency to maintain its balance factor.

Let us consider the field characteristic of an alternating current generator, that is, the interdependence of volts at the armature terminals and amperes at constant field excitation. Such a curve, the field characteristics of a 300 K. W. three-phaser used for long-distance transmission by step-up and step-down transformers,

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is shown in Fig. 14 with the ampere output as abscissæ, and volts at armature terminals as ordinates, and the K. W. output as ordinates. The ampere-volt curve is similar to a quadrant of an ellipse, that is at and near open circuit, the voltage is approximately constant for variation of current, and the machine regulates for constant potential. At and near short-circuit the current is approximately constant for varying voltage, and the machine regulates for constant current. The output of the machine, as shown in dotted line in Fig. 14, increases from zero at open circuit, reaches a maximum of 345 KW, at 575 volts

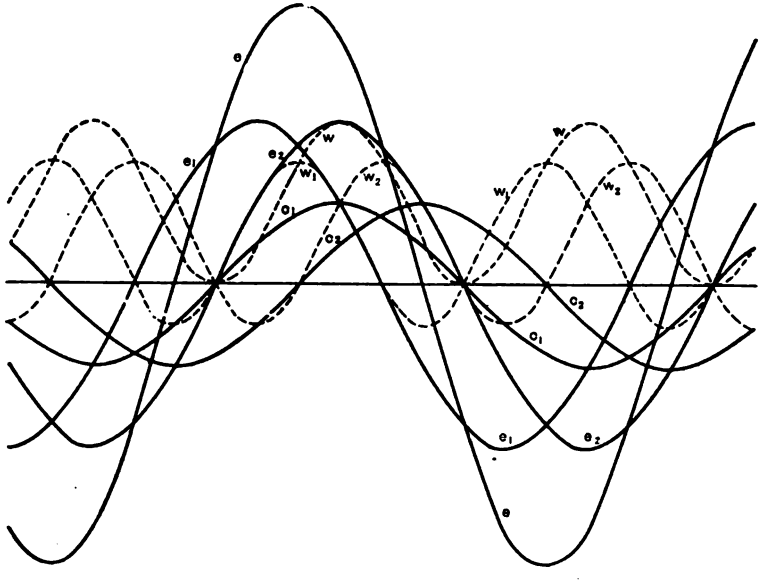

FIG. 11.

and 345 amperes, and decreases again to zero at short-circuit. Near the maximum output there is a wide range, where the machine regulates approximately for constant power. That is, an increase of current reduces the voltage, and a decrease of current increases the voltage, so as to maintain approximately constant power.

The proper working point of an alternator lies somewhat below, but quite near the maximum output point. Operating in this range near the maximum output point, but still far enough below to ensure sufficient synchronizing power for parallel running, the generator gives the best weight efficiency and energy

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efficiency, and is most reliable in its operation in-so-far as it is very easy to synchronize without too careful and delicate adjustment, the cross-currents in parallel operation are insignificant and the machine will keep in step, even under very exacting conditions, as for instance, if the field circuit of one is broken, and will not be damaged or damage the prime mover by an accidental short-circuit of the system, or a falling out of step or any other such accident.

In a polycyclic machine in this range near the maximum output point, self-regulation for constant power takes place, not only for variation of the total load, but also for variations of the load between the different circuits. Thus, in a three phaser like the present one in Fig. 14, if the load of one circuit is decreased, the voltage in this circuit will increase, and the voltage in the two other circuits change so in size and phase as to restore the system, to a certain extent, to constancy of flow of energy, or in other words:

The multiple-circuit generator regulates, or tends to regulate, near the maximum output point for constancy of the balance factor. Thus, the polycyclic machine with balanced circuit regulates for constancy of the flow of energy; the monocyclic machine regulates for a balance factor zero.

This self-regulation takes place by a change of voltage and a shifting of phase of the different generator circuits. It is therefore in general objectionable.

A similar action takes place in multiple circuit motors, induction motors as well as synchronous motors, etc.

In the multiple circuit alternating current motor, as for instance, a three-phase induction motor, the counter E. M. F.'s in the different circuits are equal (or rather proportional to the respective number of turns of the different circuits).

If the impressed E. M. F.'s are equal, the currents flowing into the motor circuits are equal also, since they are produced by the differences between impressed and counter E. M. F.'s. If, however, the impressed E. M. F.'s become unequal, even to a small extent only, the differences between the impressed and counter E. M. F.'s become rapidly very different, and the currents thus unequal. For instance, if in the three-phase induction motor one of the E. M. F.'s falls by 10 per cent. below the other two, it will be equal with, or even less than the counter E. M. F., and the circuit of this E. M. F. will take no current, or will even return

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current into the system, and the currents of the two other branches will increase correspondingly.

In this regard the multiple circuit motors are very sensitive, and a small variation in the size or the phase of the impressed E. M. F. causes a large variation in the currents, shifting the current from the branch of the low impressed E. M. F. to that of high

FIG. 12.

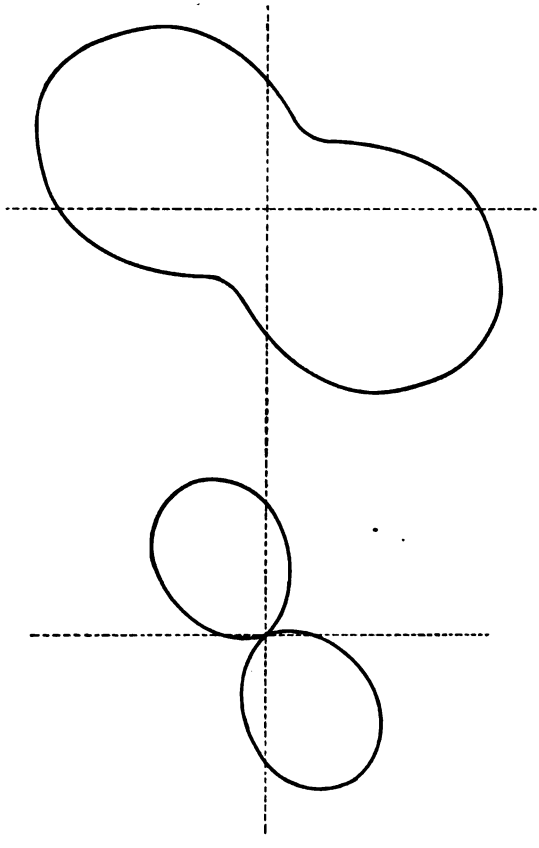

FIG. 13.

E. M. F. It is thus obvious that, with a considerable number of multiple circuit motors in the polycyclic system, even a large inequality in the distribution of the single phase consumer circuits, as lights, between the generator branches, will not unbalance the system. The generator will regulate for constant flow of

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energy and tend to raise the voltage on the lesser loaded, to lower it on the more loaded branch. The motors, however, in this case take more current from the branch of higher voltage, the lesser loaded branch, and less current from the higher loaded branch, or even return currents therein and so restore the balance of the system with regard to constancy of flow of energy and constancy of voltage and of phase relation. This feature of automatic self-regulation for constancy of flow of energy by the generator, and constancy of voltage and phase relation by the motors, is with proper design of the system very marked, and holds the system balanced very closely, even within wide ranges of load.

As before stated, this self-regulation in reality tends towards constancy of the balance factor of the system. Thus in a monocyclic system, or a system with balance factor zero, as given by a standard monocyclic machine with main or energy coil, and teaser or supplementary coil, as soon as current is taken off from the teaser circuit the voltage therein drops, and thus reduces the current, and at the same time displaces it in phase so as to maintain the flow of energy pulsating, or with balance factor approximately zero.

It will be seen that all these features are internal reactions of the alternators and multiple circuit motors and the system in general, which, while probably noticed before, have not been understood and therefore considered as objectionable features, as for instance the "unbalancing" of the generator or the "unequal distribution of current" in induction motors. Recognized in their significance, these phenomena allow a very effective and perfect control of the alternating current system.

After this diversion we may return to the motor problem. As seen, the polyphase system, characterized by a constant flow of energy, promised a solution of the motor problem for polyphase circuits. But it was not possible to produce polyphase circuits from single phase alternators without storage of energy.

Thus it remains to be seen whether those features which made the induction motor work on polyphase circuits are essential features of the polyphase system or not.

The problem of the alternating current motor may be approached from still another side, from the viewpoint of adapting the continuous current motor to alternating current cir cuits. In similar lines to this, work has been done by Vande poele, Eickemeyer, Stanley, myself, and others in this country, by Kennedy and others abroad.

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The continuous current motor, as shown diagrammatically in Fig. 15, consists of two different elements movable with regard to each other, the field and armature. Rotation of the motor is due to the action of the magnetic field upon the currents flowing in the armature. Thus, the electric circuit of a continuous current motor consists of the field exciting circuit producing the magnetic flux which passes through and acts upon the armature, and the armature or power circuit whose current is sent through the armature by the brushes in such direction as to produce a current polarization at right angles (in a bipolar motor) to the magnetic field flux. The possibility of operating such a motor

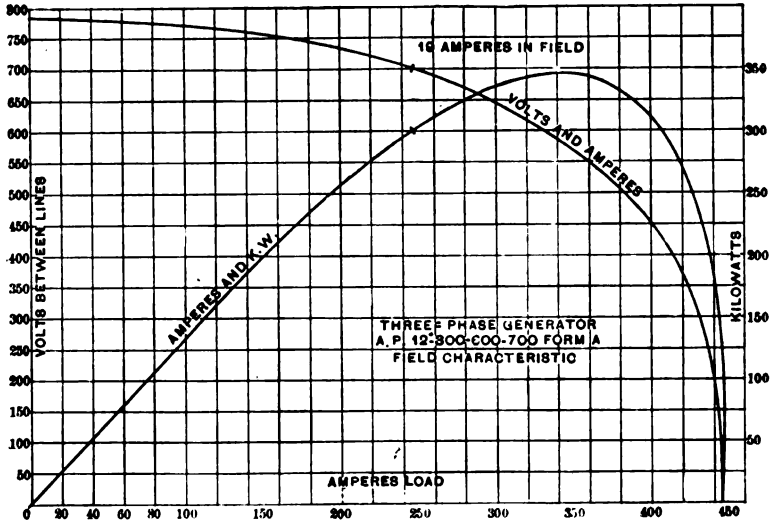

FIG. 14.

successfully is based on the feature that the armature coils when reaching the brushes are in a position where no E. M. F. is induced in them, and they can thus be short-circuited by the brushes, in their passage from the one to the other side, without sparking.

A simultaneous reversal of field magnetism and armature current does not change the direction of rotation of the motor. Thus, if an alternating current is sent through such a motor, proper care being taken to have the reversal in field and in armature take place simultaneously, the motor should be expected to operate also. Obviously thorough lamination of all the iron parts would be necessary to avoid eddy currents. Such motors, straight alter-

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nating current series motors with laminated field, have been tried but have been a complete failure in all but the smallest sizes, as fan motors, due to their excessive and incurable sparking. As seen in Fig. 15, in the moment of commutation, the armature coil encloses the whole field flux, and thus in this moment does not cut lines of magnetic force by its rotation, that is, no E. M. F. is induced therein and commutation possible[1]. If, however, the magnetic flux is alternating, the armature coil under the brush which encloses the total alternating flux, is a short-circuited secondary to the field coil as primary, and thus, independent of its rotation by transformer action, an E. M. F. will be induced therein which tends to produce a current of the same M. M. F. as the field exciting coil. A numerical instance will show how excessive this current is. Assuming the total field exciting ampere-turns only as large as the armature ampere-turns, and only 10 commutator segments between brushes, then in the short-circuited coil, we will get nearly ten times as large a current as the main current, and thus in this one coil ten times the current-heating as in the whole other part of the armature. If the armature does not start instantly, this current will burn out the coil, but even if the armature starts, vicious and destructive sparking forbids the use of such a motor.

In the continuous current motor the use of brushes and thus of a commutator, constitutes the only way to produce the current in the armature. In the alternating current motor the required current in the armature can be produced by induction, by acting upon the armature as secondary in the proper direction by a primary coil, which may either directly surround the armature, as shown in Fig. 16, or surround additional pole-pieces as shown in Fig. 17. The apparatus in this case combines the features of the alternating current transformer with those of the direct current motor. It consists of an exciting circuit, producing the magnetic flux, and an energy circuit, stationary with regard to the exciting circuit. The energy circuit induces as primary in the armature as secondary, the current acted upon by the field magnetism. The armature current is in phase with, but in opposition to the primary current. The primary current will supply the power of the motor and is thus practically in phase with the primary main E. M. F. The field magnetism will be in phase with the armature current, that is in phase with the primary current.

1. In reality the brush position is shifted intentionally so as get some E. M. F. in the armature coil, which it required for forced commutation.

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To get the field excitation in phase with the main current, the exciting current must be in phase with the main E. M. F. Since, however, in an alternating magnetic circuit, the magnetizing current lags approximately 90° behind the impressed E. M. F., it follows that the E. M. F. impressed upon the field circuit must be 90° ahead of the main E. M. F. Or in other words to produce in such a transformer motor a magnetic field in phase with the induced armature current, but displaced at right angles in space, a supplementary E. M. F. is required, approximately 90° displaced from the main or power E. M. F. Being in quadrature with its current, this E. M. F. represents no power, and thus need not be supplied by the generator, but may originate from a motor or other multiple circuit apparatus.

We see thus that the alternating current motor requires a sup-

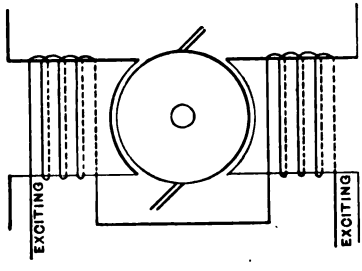

FIG. 15.

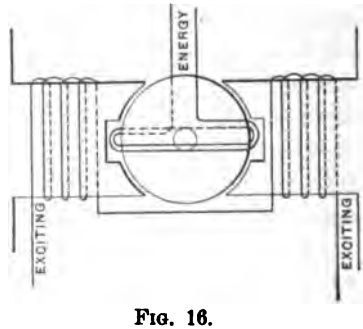

FIG. 16.

plementary circuit for its operation, the so-called "teaser circuit" of the monocyclic system. One difficulty, however, is met here. Since the movable armature acts as secondary to the stationary primary main circuit, the armature must contain a number of circuits closed upon themselves, but displaced in position from each other, so as to form in any position a secondary circuit to the primary.

In this case the armature circuit will form closed secondary circuits also to the field exciting circuits, and energy be supplied by the supplementary circuit, making this a power circuit. This would require the teaser circuit to have capacity enough to supply energy, and in short make a polyphase system. Thus, means have to be provided to avoid this feature. Since all the armature circuits pass through the same magnetic field, the E. M. F. induced therein per turn will be the same, and equal to that in the power circuit, less

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the drop of voltage by resistance and reactance. If now the voltage of the exciting circuit per turn, is greater than that of the armature, transfer of energy will take place from the exciting circuit to the armature. If the E. M. F. is the same, no transfer will take place, and the exciting current will fulfil its purpose of mere magnetization. If the E. M. F. is less, energy will be transferred backward from the armature to the exciting circuit. Thus we see that to avoid energy transfer between armature and exciting circuit, the E. M. F. of the latter per turn, must be equal to that induced in the armature. At constant impressed E. M. F. on the primary power circuit, the E. M. F. induced in the armature decreases with increasing load; that is, increasing current. Thus at constant E. M. F. impressed upon the exciting circuit, at light load, the armature E. M. F. will be higher than the exciting E. M. F. and energy be transferred backward from armature to exciting circuit. At some intermediate load, armature and exciting circuit will be equal, and at higher load the armature E. M. F. will be lower than that of the exciting circuit, and energy be transferred from the exciting circuit to the armature. In this case, all exciting circuits being connected together, this supplementary circuit acts as an equalizing circuit in transferring energy from motors operating under light load, to motors operating under overload. While this action may be advantageous to a certain extent, it is obvious that the current flowing over the equalizing circuit should be as small as possible, because if a large energy current is allowed to pass over the teaser circuit, this circuit becomes an energy circuit also, and must thus have sufficient current capacity to carry the power. That means the generator becomes more or less a polyphase generator, and a distribution of circuits between the phases becomes necessary, the very feature it is intended to avoid. For this purpose the E. M. F. at the exciting circuit is not kept constant but reduced at increasing, increased at decreasing load so as to be always very nearly equal to the armature E. M. F., and this is done by giving the teaser or supplementary circuit a sufficently large resistance and reactance, so that an increase of current drops, and decrease raises the E. M. F.

We have now arrived at the modification assumed by the continuous current motor in its adaption to alternating current circuits:

1st.—The armature current is induced by a primary energy circuit, instead of being led in by brushes.

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2nd.—To keep the field excitation in phase with the armature current, it is derived from an auxiliary circuit of displaced E. M. F.

3rd.—To avoid energy transfer between field exciting circuit and armature, the E. M. F. at the terminals of the field exciting coil is kept approximately equal to the E. M. F. induced in the armature, by the internal reactions of the system.

This is the monocyclic motor.

The calculation of such a motor is now simple, and done on the hand of the previous explanation of its action. The torque, and thus the output of the motor, are determined by the field magnetization, the armature current, and the angular space displacement between them. The field magnetization is determined by the impressed E. M. F. of the exciting circuit, and the arma-

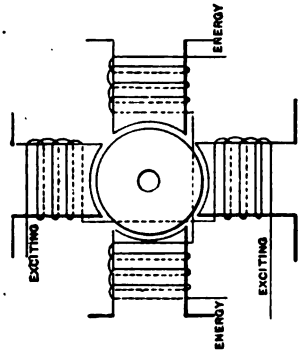

FIG. 17.

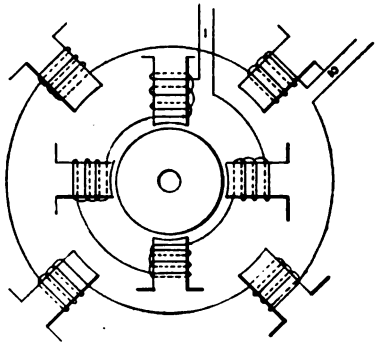

FIG. 18.

ture current is determined by the equations of the alternating current transformer, as secondary currents induced by the primary energy current. Since no energy transfer should take place between the exciting circuit and the armature, it follows that the counter E. M. F. at the exciting circuit, is equal to the E. M. F. induced in the armature, and thus the magnetic flux can be calculated from the latter.

This leads us to the theory of the induction motor as outlined by me in the TRANSACTIONS of 1894 p. 669, equations as seen strictly analogous to those of the alternating current transformer.

Since the E. M. F. required at the terminals of the exciting circuit, in such a motor, is in quadrature with the main E. M. F., obviously such a motor could be operated from a quarter-phase

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circuit also. It would in this case, however, offer the disadvantage of loading the two circuits unevenly, the one circuit with a large energy current in phase with the E. M. F., the other circuit with a small and lagging exciting current.

An equal load on both branches of the system can be secured by using a double motor. In this case the first phase is used to feed the energy circuit of the one, and the exciting circuit of the other motor, the second phase for feeding the exciting circuit of the first, and the energy circuit of the second motor. Going still a step further, one and the same field pole can be used for exciting the field of the one, and inducing the armature currents of the other motor, by cross-connecting the armature, or using one armature within two fields placed side by side of each other, as outlined diagrammatically in Fig. 18. As you see, we get here our well-known friend the Stanley motor, consisting of two armatures with common winding acted upon by two fields, in such a way that each field sends the magnetic flux through the armature, and at the same time induces currents in the armature winding which are acted upon by the magnetic flux produced by the other field.

Going still a step farther in this direction, one armature only may be used in one double field, by bringing both sets of field poles into the same plane as shown diagrammatically in Fig. 19. Here we have two magnetic field fluxes in quadrature with each other, each acting upon the currents induced in the armature by the other flux. Obviously it is unessential theoretically whether we have a double motor with two fluxes in quadrature, or a triple motor with three fluxes under equal angles. The equations of the motor and its calculation remain the same as mentioned above.

As seen, starting from the continuous current motor, by successive steps we arrived at the so-called "rotary field motor" without making use of the hypothesis of the revolving field. In the last type of motor and to a lesser extent in the preceding types, the action of the motor can also be explained thus:

The E. M. F.'s of displaced phase impressed upon the motor circuits, produce currents in these circuits which combine in their magnetizing action to a resultant M. M. F. This resultant M. M. F. rotates at constant, or approximately constant, intensity, and at a uniform velocity, the velocity of synchronism, through the motor field, and produces thereby a system of rotating magnet

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poles, which by their drag upon the currents induced by them in the armature, cause the armature to revolve. This theory is very beautiful by its simplicity. It has, however, the disadvantage of not giving due prominence to the transformer feature of the motor and to the multiple circuit feature. Therefore, it has not proved suitable as far as I know for the calculation of such motors, and has in this regard rather retarded the progress of induction motor design, by deflecting the attention from the multiple circuit transformer feature of the motor. If, for instance, in the motor in Fig. 19, one of the circuits was opened, the field should be expected to change from rotating to pulsating, that is varying between maximum and zero. It does not change, however, but remains the same. But under certain circumstances, the rotation of currents may even be in opposition to the rota-

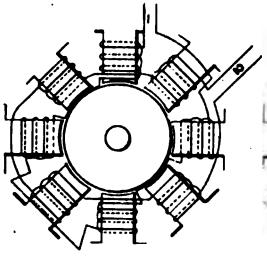

FIG. 19.

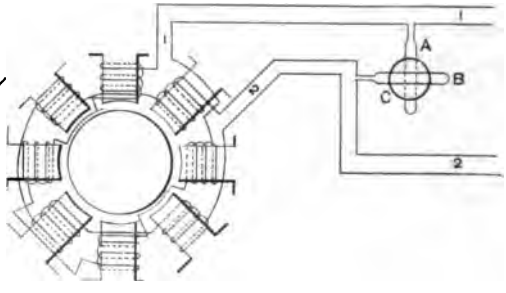

FIG. 20.

tion of the motor amature. Inserting in the two circuits of the motor in Fig. 19 a field exploring device consisting of two small coils A and B, Fig. 20, in quadrature with each other, and with a light movable iron disk C in their common center, we can by the rotation of this iron disk find the so-called rotation of the currents in the two circuits, and its direction. If equal E. M. F.'s are impressed upon the two circuits of the motor, the iron disk C will rotate rapidly in the same direction as the motor armature. Reducing one of the two E. M. F.'s gradually, we should expect to see the rotating field change from uniform rotation to elliptical rotation, so that, for instance, if B is 10 per cent. lower than A, the "rotating field" should pulsate by 10 per cent. In reality the action of the motor is such as would require a constant and uniformly rotating field for its explanation.

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The strangest feature, however, is the behavior of the iron disk C. With increasing difference between the E. M. F.'s, A and B, the disk slows down, comes to rest, and then begins to revolve in the opposite direction, showing that one of the currents has reversed, and the direction of rotation of the primary currents in the motor and thus their M. M. F's. is reversed. The motor, however, keeps on revolving in the same direction as before, that is in opposite direction to the primary currents. The explanation of this phenomenon follows from the preceding discussion of the multiple circuit transformer feature of the motor. With the decrease of the E. M. F., B, the transformer action between armature and circuit B reverses its sign, and current returns from B. Thus, with increasing difference between A and B, the current A constantly increases while B decreases, reaches a minimum when the exploring disk C stops, and then increases again. This experiment is very instructive in showing the internal reactions of the induction motor.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

SOME OBSERVATIONS ON A DIRECT-CONNECTED 300 K. W. MONOCYCLIC ALTERNATOR.

BY DUGALD C. JACKSON AND S. B. FORTENBAUGH.

Before giving the results of the observations we have taken, it will probably be desirable to give a brief description of the machine.

The machine is the new monocyclic alternator, manufactured by the General Electric Company, of 300 K.W. capacity—1150 volts, 260 amperes—at a speed of 140 revolutions per minute. It is direct connected to a Russell, tandem-compound, high-speed condensing engine, which ran during the test about 15 revolutions more than the required speed. The armature is of the ironclad type, 110 inches in diameter, 10½ inches wide, with about $\frac{3}{16}$ inch clearance, and is furnished with two sets of windings.

According to Dr. Louis Bell the cross-section of the main and teaser coils is the same, but the latter has fewer turns and is placed in shallower slots midway between the main coils. The pressure developed by the teaser coils was .7 of the pressure across the main terminals of the machine. There are 96 slots on the armature, one-half of these being used for the main coils and the other half for the teaser coils. Three collector rings are used, one being connected to each end of the main coil, and one to the free end of the teaser coil. These are made of brass, 2 inches wide and $\frac{3}{4}$ inch thick, and each has two brushes, $\frac{5}{16}$ inch thick, covering its full width. The rectifier for the series excitation is 4¾ inches wide and has 48 segments 1¼ inches in width. Two sets of brushes are used for both the positive and negative poles of the rectifier, each set consisting of two copper brushes 1¾ inches wide by $\frac{5}{16}$ inch thick. Only about .63 of the total cur-

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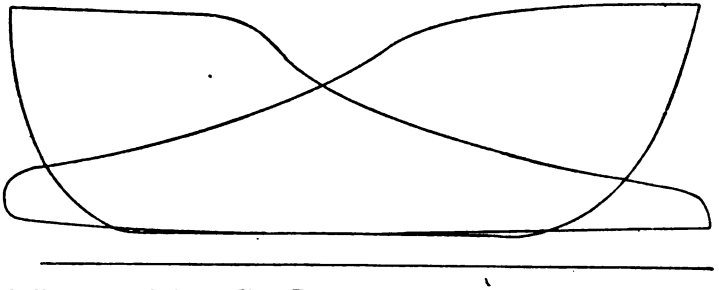
rent is rectified in this machine. The magnet cores are laminated, 48 in number, and are 10 by 4¼ inches face and 10¼ inches deep, the outside dimensions of the field windings being about 12 by 6 inches. Each magnet spool carries a series coil, and a separately excited coil, all the series and separately excited coils being separately connected in series.

The series coils are formed of two flexible cables in parallel, having a total cross-section of about 98,000 cir. mils. while the cross-section of the separately excited coils is about 33,100 cir. mils.



Indicator Card from High Pressure Cylinder, 60 lb Spring. Speed 146. Total I H. P., High Pressure 126.8 E. H. P. 190.

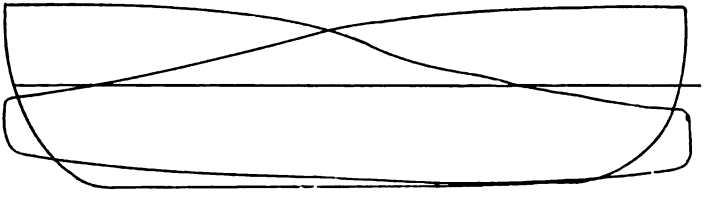


FIG. 1. Indicator Card from Low Pressure Cylinder, 20 lb. Spring. Speed 146. Total I. H. P. Low Pressure Cylinder 107.8 E. H. P. 190.

The exciter used was a four pole continuous current machine, of the new General Electric. slow-speed type, belted direct from the dynamo shaft, and therefore all power measurements include the power furnished to the exciter. The output of the exciter is 52 amperes at 125 volts, and its speed 850 revolutions per minute. Standardized Weston instruments were used, with the exception of the main ammeter in the generator circuit, this being the regular station instrument furnished by the General Electric Company. This instrument was quite sensitive, and, while no means were at hand for calibration, we think the results

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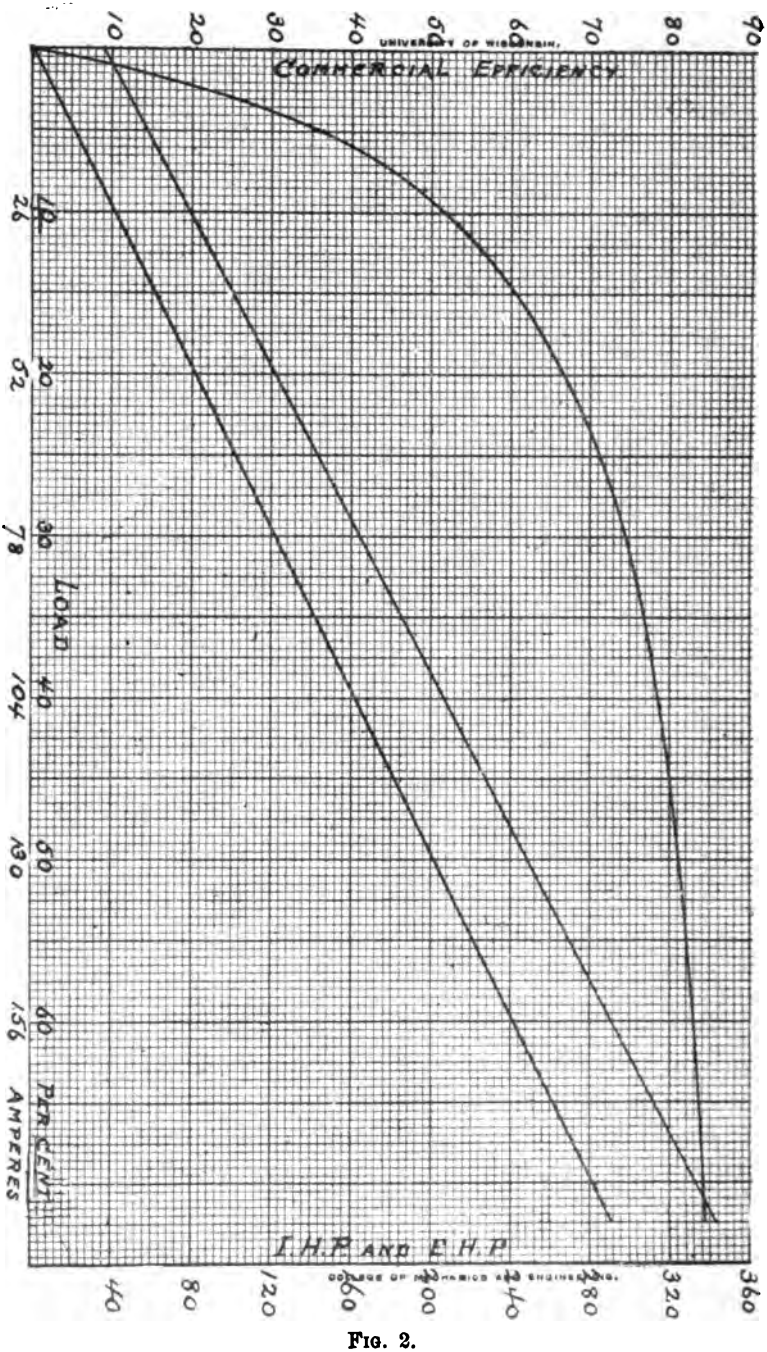

FIG. 2.

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may safely be taken as a fair indication of the performance of the machine. The principal dimensions of the engine are as follows: Stroke 24 inches, diameter of high pressure cylinder 15 inches, diameter of low pressure cylinder 24 inches.

Figure 1 represents a set of cards taken from the engine and following are the electrical readings taken at the same time—124 amperes, 1144 volts, 146 revolutions per minute. The exciting current was 51 amperes.

In planning the test we fully expected to make a ten-hour continuous run at full load, and determine the heating, efficiencies, etc., but were unable to go farther than slightly above half load. In the first place the engine was piped to a single boiler of insufficient capacity, and secondly, the engine was too small to carry the full load of the generator, and in addition its regulation was defective, the total variation of speed being as much as 15 per cent. Figure 2 therefore shows an efficiency curve for slightly above half load, and from this it will be seen that the commercial efficiency of the generating set is about 81 per cent. at half load. When these observations were made, the machine was in commercial service with the regular transformer load. The commercial efficiency of the generating set is taken as the ratio of the electrical output to the I.H.P. The E.H.P. here used is taken as the product of amperes and volts, the power factor of the circuits therefore being assumed at 100. Actual measurements have shown that the power factor is at any rate over 98 per cent., and consequently the error made by this assumption is comparatively small. The diagonal lines in the figure show respectively the I.H P. and the E.H.P. at different loads, the vertical scale for these being at the right hand of the figure. For the ordinary changes of load, the regulation of the alternator is not entirely effected by the series coils as the machine now stands, but requires considerable hand regulation. However, this can probably be improved by altering the shunts across the rectifier and series turns respectively, thus giving a greater number of ampere-turns in the series coils. This lack of regulation on the part of the alternator combined with the unsatisfactory regulation of the engine, makes the performance of the generating set somewhat below the standard for this class of machinery when under ordinary working conditions, but, as a whole, the unit is a magnificent piece of mechanical construction.

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Discussion.

Mr. E. J. Berg :—This paper states that the cross-section of the teaser coil was about the same as that of the main coil. It ought to read one-quarter. The cross-section of the conductors in the teaser coil is the same as the cross-section of the conductors of the main coil, but the number of turns of the teaser winding is only one-quarter of that of the main winding, and thus the total cross-section is but one-quarter that of the main coil. In consequence thereof, the e. m. f. of the teaser coil, which is stated in the paper to be .7 of that of the main coil, is only .25. The e. m. f. observed by the writer of the paper is probably the difference of voltage between main and teaser collector ring, and thus is at open circuit .57 of the potential between the mains.

Mr. Gano S. Dunn :—I would like to inquire the reason for such a high power factor with the conditions under which the machine was running?

Prof. Fortenbaugh :—The ower factor was determined by using a large wattmeter, after being carefully calibrated, and simply taking the ordinary meter readings, amperes and volts.

The ratio of the product of the amperes and volts to the wattmeter readings gave us the power factor of about 98½ per cent. The machine was in ordinary commercial lighting service, and these readings were taken on only one of the regular lighting circuits, and assumed to be practically the same on all of them.

I am much obliged to the gentleman who made the corrections. In regard to the cross-section of the main and teaser coils, I will simply say that my information was taken from an article by Dr. Louis Bell, which, I think, was recently read before The National Electric Light Association.

As regards the ratio of the pressures between the mains and teaser wire, I have here one reading in which the e. m. f. between the terminals is 1,100 volts, and that between the teaser and either one of the terminals is 760. This gives a ratio of about .7 approximately, with no current on the teaser wire. It may not be absolutely correct, but that is a fair average reading on this particular machine.

The generator load corresponding to these readings was 160 amperes, and the current in the series field was 104 amperes.

Mr. Steinmetz :—I think I can explain a part of this discrepancy regarding the voltage between the main and teaser collector ring. As I showed in my last paper, there is a tendency in the alternating current generator to regulate for constancy of balance factor. This means that in this particular case, if the generator main coil is loaded, the main voltage will drop more than the teaser voltage, or in other words, since the machine is compounded, the teaser voltage will rise, and thus give a somewhat greater difference of potential between main and teaser coil. Inversely, if the teaser coil is loaded, as by induction motors, its

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voltage will drop, and so the ratio between teaser voltage and main voltage be reduced. This is plainly shown in the variations of terminal voltages on an induction motor operated from the monocyclic system. I have here (Fig. 1) the characteristic curves of a standard 15 H. P. induction motor operated from a monocyclic generator by means of two transformers connected with their primaries between teaser and main line, while one of the

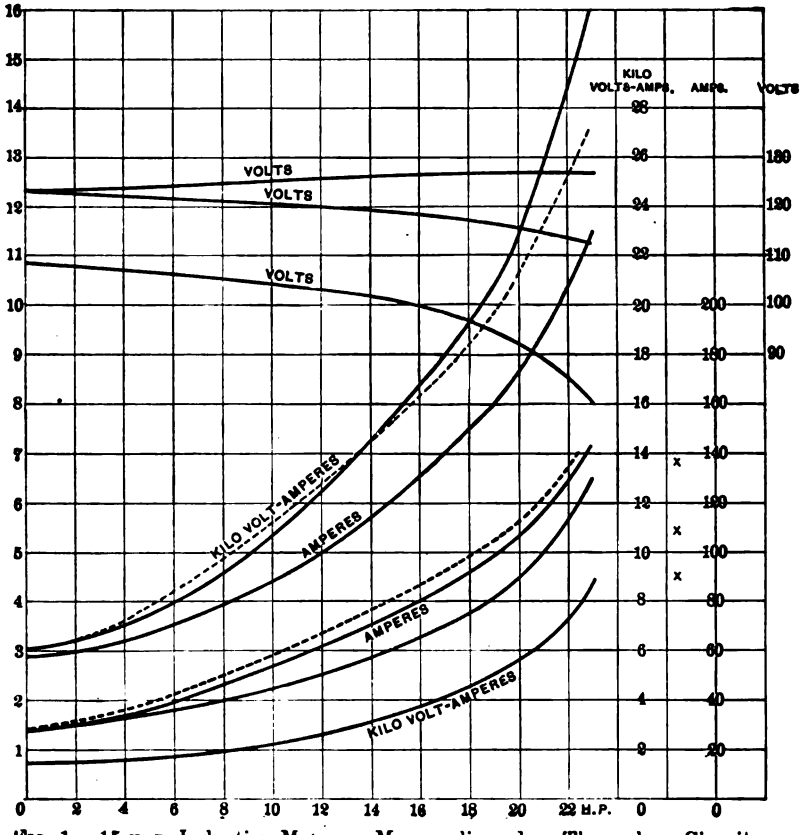

FIG. 1.—15 H. P. Induction Motor on Monocyclic and on Three-phase Circuits.

secondaries is reversed with regard to the other, thereby changing the relative displacement of the E. M. F.'s from approximately 60° in the primary to approximately 120° in the secondary, and giving approximately an equilateral triangle. At no load, the three secondary E. M. F.'s are, as seen from the diagram, 124, 124 and 109 volts, the lowest E. M. F. being that corresponding to the teaser voltage. With increasing load on the motor, and increasing current taken by it, the teaser voltage drops rapidly and

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reaches 80 volts at 22½ H. P., while the two other voltages, which are composite voltages, or resultants of main and teaser voltage, have changed to 127 and 113 volts. The difference between them is due to the interaction of main and teaser circuit caused by the tendency of the generator to maintain its balance factor. Incidentally I may remark that on the same curve sheet are shown in drawn lines the amperes consumed by the motor, the large value representing the common return of the two essentially single-phase currents. The apparent kilovolt-amperes of the main coil and of the teaser coil are given by two thin drawn lines. For comparison, in dotted lines are given the amperes and kilovolt-amperes consumed by the same motor when operated on a three-phase circuit.

Now with regard to the other question, the voltage measured between main collector ring and teaser collector ring cannot be

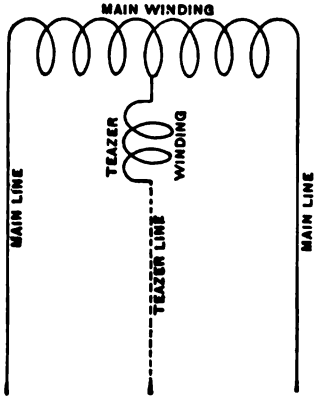

FIG. 2.

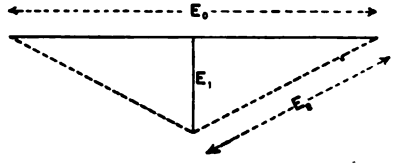

FIG. 3.

properly called teaser voltage, since it is a resultant voltage of the teaser coil and half the main coil. The teaser voltage cannot be measured directly, since only one terminal of the teaser is brought out to a collector ring, while the other terminal is connected to the middle of the main coil as shown in Fig. 2. Thus, to determine the teaser voltage we can either proceed by calculation by measuring the voltage between teaser collector ring and main collector ring, $= E_2$ and the voltage between the main collector rings $= E_0$. The teaser voltage is then

$$E_1 = \sqrt{E_2 - \left(\frac{E_0}{2}\right)^2}$$

as seen in the E. M. F. diagram Fig. 3. Another way to determine the teaser voltage by measurement, is to separate it from the main voltage by transformation, by connecting two trans-

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formers between teaser and main lines and reversing the secondary of one transformer as shown in Fig. 4. We thus get the primary E. M. F., diagram Fig. 5, where A B is the main voltage, C D the teaser voltage, and A C and B C the two voltages between teaser and main coil, that is the voltages at the transformers. The reversal of the one transformer, reverses one of these E. M. F.'s B C, and thus gives the secondary E. M. F. diagram *a b c*, and in this diagram which is approximately an equilateral triangle, the

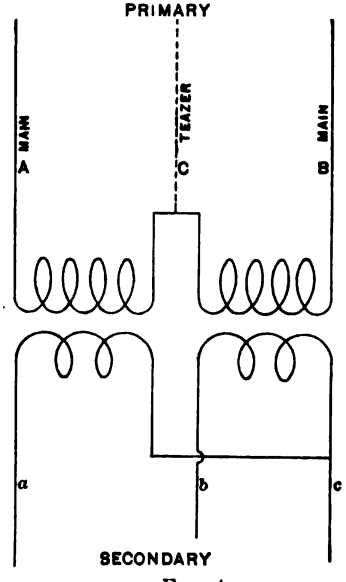

FIG. 4.

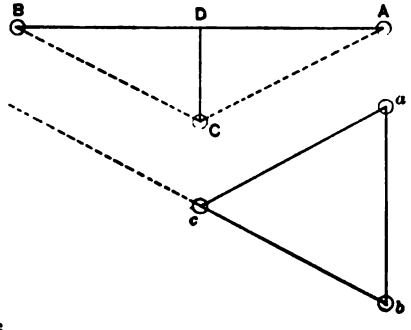

FIG. 5.

smallest side *a b* is equal to twice C D, that is twice the teaser voltage, times the ratio of transformation. In this way the teaser voltage can be separated by transformation.

PROF. FORTENBAUGH:—In this paper we should have stated that the ratio of the pressures was about .7 with no load on the teaser wire. We had no way of measuring this pressure when the teaser wire was loaded, simply because it was not in use.

(Recess till 8 P. M.)

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 26th, 1895 President Duncan in the Chair.

THE COST OF STEAM POWER. II.

BY CHAS. E. EMERY, PH. D.

§ 1. Previous articles of the writer on this subject dealt with the problem as it practically presented itself at the several times. The first article in 1883[1] referred particularly to results which had been obtained in a number of typical cotton mills by the use of the ordinary condensing engines in vogue at the time. A more recent article in 1893[2] discussed the question of the cost of steam power in 500 H. P. units or multiples of the same, developed in different kinds of engines, including the more modern triple compound engines. The first paper was based on actual conditions, the second on assumed conditions, the best experimental results being considered, but afterward modified by judgment so as to give a final result which would approximate the conditions of ordinary average working. In a later and more general article published in 1895[3] the method employed to increase experimental results to an approximately practical basis was outlined, but otherwise the inquiry was extended little or no further than before.

§ 2. In connection with the proposed supply of power in large units from Niagara Falls and other undertakings of a similar character, the question naturally arises: What would be the cost of steam power if also supplied in large units and generated with modern machinery of the most approved type? The question would be a simple one if it involved only the amount of coal consumed at a definite price, and the labor required to handle

1. Trans. Am. Soc. C. E., vol. xii., p. 425, Nov. 1883.
2. Trans. Am. Inst. El. Engrs., vol. x., p. 119, March, 1893.
3. *The Engineering Magazine*, vol. viii, p. 796, Feb. 1895.

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the coal and attend to the machinery. It is very common to compare the value of two engines simply by the relative amount of coal consumed, assuming that other costs incident to the development of the same power will be the same in all cases. Even if the assumption be substantially correct it has a more important bearing on the result than appears at first sight. The cost of coal is for ordinary engines of moderate size only about one-third of the total cost of steam power, so, if the other costs remain nearly constant, moderate savings in the cost of coal will not proportionally decrease the cost of the power.

§ 3. In large plants operated nearly at full capacity, the best types of steam machinery can be profitably employed, the cost of superintendence will be reduced and the cost of labor required for operation materially decreased. The decrease in labor depends largely on the size of steam unit it is found practicable to employ. Triple compound engines of 10,000 to 15,000 H. P. each, are used quite successfully in our large ocean steamers, but it is considered that these units are altogether too large for the problem we are considering.

§ 4. Any supply of power must be adapted to the nature of the demand, which for most industrial operations is variable, and it is desirable to make the steam units of such size that one or more of the same can be grouped together to carry the load at any time, without either overloading or greatly underloading either of such units. In a large plant, upon which presumably many different manufactories depend for power, there should be a spare unit which can be used in case of accident, and ordinarily employed in regular turn, so that all the machinery can be kept in repair.

§ 5. It will thus be seen that the size of the units is limited by the conditions above stated. If 20,000 H. P. as a maximum were to be delivered, two units of 10,000 H. P. each would do the work, but evidently the spare engine would require also to be 10,000 H. P. and this would involve too large an amount of capital in spare machinery. At Niagara Falls four connected turbines and dynamos of 5,000 H. P. each are being erected in a preliminary plant, so that only 15,000 H. P. maximum can be delivered if the principles above outlined are strictly carried out, though evidently contracts can be drawn to provide that the power may be stopped in case of accident, the same as in a private establishment, and thereby all the wheels and engines put

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in service at the same time, but it is probable that one unit will be practically kept in reserve and more units added as the demand warrants. With steam power there would be some advantages for a 20,000 H. P. plant in adopting a unit of 2,500 H. P., on which basis with one spare unit of this size there would be nine such units in all. There is an advantage in having all the engines alike, as the parts required for repairs are then duplicates of each other, the units can be more suitably arranged in the building, and the labor better distributed. When it could be done without too much detail, it would be desirable to couple together several engines of 2,500 H. P. each, so that they would be capable also of independent operation. Another method would be to disregard absolute uniformity when so much power is to be delivered, and have several duplicates of two different units, say one of 2,500 H. P. and another of 5,000 H. P., which would either require the size of the spare engine to be increased, or that the other engines be slightly overworked in case of accident. For simplicity, however, all the costs will be assumed alike with either arrangement.

§ 6. The average cost per H. P. when the load is variable is considerably greater than if the power be furnished continuously. Coal is wasted in building up the fires and in caring for them when not required, all supplies are increased from the necessity of starting new after every stoppage, and there is an important loss due to the interruption of the regular hours of labor. A sufficient force must be kept on hand at all times to provide for any demand, and the watches of the men arranged in some practical way so as to proportion the labor to the work to be done as nearly as possible.

§ 7. It is desirable at the outset, however, to ascertain what steam power will cost under the most advantageous conditions as to demand, and we therefore submit a preliminary estimate based on the assumption that 20,000 H. P. can be sold for every hour in the year. The details of the estimate are discussed afterward.

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§ 8.

TABLE I.

SHOWING COST OF STEAM POWER ON BASIS OF GENERATING 20,000 H. P.

CONTINUOUSLY EVERY HOUR IN THE YEAR.

			Per Cent. of Total Cost.
	Yearly cost of coal for 20,000 net H. P. operated continuously every hour in the year, based on a consumption of 1.25 pounds of coal per indicated H. P. per hour, § 10. Cost of coal assumed at one mill per pound, or $2.24 per ton,		
1.	§ 12. Engine efficiency assumed at 92.3 per cent, § 11..	$237,250	43.4
2.	Estimated cost of labor, § 13.....	60,444	11.1
3.	Estimated cost of supplies and regular repairs, § 14.....	105,120	19.2
4.	Estimated interest, insurance, taxes and cost of renewals, § 15—16.....	144,000	26.3
5.	Total..... ...	$546,814	100.0
	Which divided by 20,000 gives the following:		
6.	Cost of steam power per H. P. per year, on basis of 20,000 H. P. delivered every hour in the year.....	$27.34	
7.	Cost of steam power per H. P. per year on above basis, if 5 per cent. of the original cost of plant, § 16, be charged for dividends, and $1.00 per H. P. added for general business expenses, § 18 ..... 27.34 + 3.60 + 1.00 =	31.94	
8.	Cost of steam power per H. P. per year on above basis, if 10 per cent. of the original cost of plant, § 16, be charged for dividends. and $1.00 per H. P. added for general business expenses, § 19 ..... 27.34 + 7.20 + 1.00 =	35.54	

§ 9. This cost is, for reasons which will be discussed later, lower than it is probable any plant can be operated under commercial conditions. This price is somewhat higher than those given in the papers previously mentioned, simply because operation is supposed to be continued every hour in the year.

§ 10. The cost of coal above outlined is derived as follows: The best triple compound engines have developed a H. P. for a little less than 12 pounds of water per H. P. per hour, and boilers have been constructed which at actual pressure from actual temperature of feed, evaporated 10 pounds of water per pound of first quality coal. Both these results are under experimental conditions, but we must assume that in a large plant like this, all details will be so well attended to that fair experimental results may be obtained all the time. We therefore assume that the power will be produced regularly for $1\frac{1}{4}$ pounds of coal per indicated horse-power per hour which would be obtained with engines requiring $12\frac{1}{2}$ pounds of feed-water per H-P. if the boilers evaporated 10 pounds of water per pound of coal, or if the boilers evapora-

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ted 9.6 pounds of water per pound of coal and the engines only required 12 pounds of water per H. P. per hour.

§ 11. For permanent work of the kind assumed, engines of comparatively slow speed should be selected and, although some of the work might be directly connected, part of it at least would necessarily be operated by some method of transmission. The frictional losses of the engines and the more important features of transmission to the work done have been assumed at 7.69 per cent., so that the amount of coal per indicated horse-power above assumed must be increased by $\frac{1}{13}$ to give the coal per net H. P.

§ 12. The cost of coal per ton varies greatly in different parts of the country. The actual cost of mining bituminous coal is as low as 25 cents per ton in some locations, and the coal can be delivered on the cars at a good profit at 50 cents per ton. At deep mines the cost of mining is greater, but in all cases the principal cost of coal is the transportation, which has been reduced from time to time by increasing the size of the coal cars and the weight of the train, and by reducing the grade in the direction of traffic, until it is credibly stated that coal can be hauled on the main trunk lines, at a profit, for one-half cent per ton per mile, thus adding only $0.50 per ton for each 100 miles of haul. The lateral roads with undulating grades cannot haul coal at as low a rate as this. There is, moreover, to be added the general selling expenses, so it has been assumed that along the lakes, although comparatively near coal mines, the best quality of coal will cost but little over $2. per ton if purchased in large quantities, though this price must be increased on the seaboard fully 75 cents, and for ordinary consumers, of course much more. The price upon which comparison has been made is one mill per pound or $2.24 per ton, to include the cost of delivery directly in front of the boilers. The cost in line 1, § 8, is derived simply by multiplying the net power, 20,000, by $1\frac{1}{4}$, the coal per indicated horse-power, adding $\frac{1}{13}$ to allow for friction, and multiplying the result by 8760, the number of hours in the year, and $0.001, the price per pound. It appears that some kinds of coal can now be bought in Buffalo for $1.50 per ton. Adding only 25 cents per ton for the delivery of such coal directly in front of the boilers, and the taking away of the ashes, both of which are included in the price $2.24 given above, the cheaper coal need only have an evaporation of $10\ (1.75 \div 2.24) = 7.81$ pounds of water per pound of coal to make the total cost of the coal the same as for the higher priced

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coal with an assumed evaporation of 10 pounds stated in § 10. It is much more probable that 7.81 pounds evaporation will be obtained from commercial coal, than that 10 pounds will be obtained, on the average, from a higher priced coal, so the cost of coal stated in line 1 of the several tables is a fair one for existing commercial conditions. The next item, that of labor, is made up as follows:

§ 13. Without attempting to arrange watches, it is assumed that on the average there would be required in such a station at all times

One attendant for each 2,500 H. P. engine, or 8 men in all, at 25 cents per hour	$2.00
14 firemen and 3 additional men at the same pay to care for pumps, etc., and to keep the premises clean; total, 17 men at 20 cents per hour	$3.40
Total cost of labor per hour	$5.40

There would also be required a chief engineer, 3 assistant engineers and some clerical help, which under the head of superintendence would cost, say, $13,140 per year, or $1.50 per hour, making a total of $6.90 per hour. The total cost for labor and superintendence for one year of 365 days, or 8760 hours, at $6.90, is $60,444 as given in line 2 of § 8.

§ 14. The cost of supplies and repairs in connection with the boilers and large condensing engines in the cotton mills of Fall River, proved upon investigation several years ago to be approximately $\frac{6}{10}$ of a mill per H. P. per hour. With the hope that this cost can be reduced in an immense plant of this kind the quantity in line 3 has been extended on the basis that the cost will be only 0.6 mill.

20,000 H. P. × 8760 hours × $0.0006 = $105,120, as written in line 3 of § 8.

§ 15. The above estimates only provide for regular repairs. Independent of this, a certain percentage oft he first cost should be put at interest every year to provide for renewals of the machinery, and provision made also for paying taxes and insurance. Calling these three, 5 per cent. of the cost, and considering that a company which can build so large a plant can possibly borrow money at 5 per cent., 10 per cent. of the total cost will be required for these several items.

§ 16. The total cost of such a plant cannot be determined accurately in advance. The present prices for steam machinery

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are very low, and it might be possible to buy engines of the best type with necessary boilers, ready for erection for $30 per H. P. To this price, however, must be added the cost of the land upon which the plant is to be erected, the cost of foundations, of erection, of the buildings, of the chimney, the pipe connections, the general means of transmission, and the multitude of minor details required for fitting up such a place ready for use. The probable cost has been fixed at $64. per H. P. and as at least $\frac{1}{8}$ surplus power will be put in the station, there will be required a steam plant of 22,500 H. P. which at $64. will cost complete $1,440,000, 10 per cent. of which as required above is written in line 4, § 8.

§ 17. Referring to line 6, § 8, we find that the "Cost of steam power per H. P. per year on the basis of 20,000 H. P. delivered every hour in the year" is $27.34. The price at which this power can be sold to consumers, will depend upon the way the company furnishing the power is organized. The interest on the cost is already provided for in line 4, so the net cost given, viz: $27.34, would be that chargeable to power if the same company that built the works used the power, or if an association of individuals should build the plant and simply charge themselves with its cost.

§ 18. If, however, a private company with ample means should build the plant on a cash basis and wished to sell power and realize a return of 5 per cent. on first cost, independent of interest on the money invested, the modified cost would be $27.34 plus 5 per cent. of ($64 \times 1\frac{1}{8} =$) $72. (§ 16) viz $3.60, to which should be added, say, $1 per H. P. for general business expenses, making the total charge $31.94 shown in line 7, § 8, the same method being used in reference to similar lines in Tables II. and III.

§ 19. If, however, the promoters desired 10 per cent. profit on original cost, or a proportionally less percentage on stocks and bonds issued in excess of first cost, the modified cost per H. P. per year would be $27.34 plus 10 per cent. of $72. (§ 18) viz $7.20, to which adding $1 per H. P. as before, for general expenses gives as the total charge under these conditions $35.54, shown in line 8, § 8, the method applying to Tables II. and III. as above explained.

§ 20. We are now prepared to ascertain the variations in result which would be produced if the power were considered variable. For this purpose let us assume there will be sold:

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	H. P. Hours.
1. 20,000 H. P., 10 hours per day	200,000
2. 12,000 H. P., 10 hours per day	120,000
3. 5,000 H. P., 4 hours per day	20,000
4. Total daily H. P. hours	340,000

which would probably be required on, say, 309 working days in the year.

5. Total H. P. hours, 309 days	105,060,000
Then if 5,000 H. P. were required for the remaining 56 holidays in the year :	
6. Total H. P. hours, 56 days of 24 hours, 5,000 H. P	6,720,000
7. Total H. P. hours per year	111,780,000
Average H. P. per hour duriug the year :	
8. Previous result ÷ 8760 =	12,760 H. P.

The average H. P. is therefore 63.80 per cent. of the maximum. This percentage is frequently termed the "power factor," and is rather higher than has been found in practical cases heretofore. An estimate of the cost on this basis will be given in advance as before, and explained afterward.

§21.

TABLE II.

SHOWING THE COST OF STEAM POWER ON BASIS OF GENERATING 20,000 H.P. MAXIMUM, AND AN AVERAGE OF 12,760 H. P. FOR EVERY DAY IN THE YEAR.

		Per cent. of total cost.
1. Yearly cost of coal, § 22	$157,644	37.3
2. Estimated cost of labor, § 23	47,652	11.3
3. Estimated cost of supplies and regular repairs, § 25	73,584	17.4
4. Estimated interest, insurance, taxes and cost of renewals § 26	144,000	34.0
5. Total	$422,880	100.0
Which divided by 12,760, the average H. P., § 20, gives the following :		
6. Cost of steam power per H. P. per year on basis of delivering 20,000 H. P. maximum and an average of 12,760 H. P. for every day in the year		$33.14
7. Cost of steam power per H. P. per year on above basis if 5 per cent. of the original cost of plant be charged for dividends and $1 per H. P. added for general expenses, § 18, 33.14 + 3.60 + 1.00 =		37.74
8. Cost of steam power per H. P. per year on above basis if 10 per cent. of the original cost of plant be charged for dividends and $1 per H. P. added for general expenses, § 19, 33.14 + 7.20 + 1.00 =		$41.34

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§ 22. The cost of coal is made up as follows: By reference to § 20 it will be seen that 15,000 H. P. of boilers out of 20,000 must be shut down daily for periods varying with the demand, and it is considered that it will require an amount of coal equal at least to the average consumption for one hour during regular operation, to maintain banked fires, overcome radiation, and bring the fires to average working condition when they are again put in operation. The total daily H. P. hours in line 4, §20, is therefore increased 15,000 and multiplied by 309; the horse-power hours for the 56 holidays, line 6, are then added to the same; the sum multiplied by 1.25 pounds of coal per H. P. and by one mill per pound and one-twelfth added to the whole for friction, which gives the result written in line 1, § 21.

§ 23. The labor cannot be distributed accurately until the variations of loading are developed practically. On any definite basis, such as is assumed in § 20, the watches could be arranged so that there would be little loss of time, but in practice there would be a variation of load at the same hour on different days. For instance, with the electric lighting part of the load, the demand would vary with the weather; with the cable or electric railroad portion of the load the demand would be greater on particular days and seasons, and vary also somewhat with the weather, so to be provided for unexpected demands, there must be a surplus of labor. Such surplus will be assumed at 20 per cent. for the 14 hours of reduced power per working day, shown in § 20, lines 2 and 3, equivalent to labor for 28,000 H. P. hours per day, or 8,652,000 H. P. hours for 309 days. Adding only 10 per cent. for 56 holidays gives 6,720,000 × 1.1 = 7,392,000 H. P. hours. Adding both to the total H. P. hours, § 20, viz.: 111,780,000, gives a total for the year of 127,824,000 H. P. hours, which at $0.00027 per H. P. per hour (= $5.40 ÷ 20,000) easily derived from § 13 gives:

Cost of labor per year	$34,512
Cost of superintendence per year, from § 13	13,140
Total for labor and superintendence per year as written in line 2, Table II., § 21	$47,652

§ 24. The cost of labor and superintendence above is 100 × $47,652 ÷ 60,444 = 78.83 per cent. of that required for full operation throughout the year shown in § 8, although the average power developed is only 63.80 per cent., § 20.

§ 25. The cost of supplies and regular repairs, line 3, will be

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somewhat greater proportionally than for continuous operation, and is estimated to be 70 per cent. of the similar costs given in § 8, $105,120 × 0.70 = $73,584, which is written in line 3, § 21.

§ 26. Evidently the interest, insurance and taxes given in line 4, § 8, are not modified, and the percentage allowed for renewals is so small as not to materially affect the result, so the amount given in line 4, § 8, is repeated in same line of Table II.

§ 27. The presentation in Table II. will give a fair idea of the prices it would be necessary to secure on installing a large steam plant to furnish power in various quantities to consumers on the premises, or to apparatus for transmitting power to the same, the costs of which transmission are not included. The costs at which the power can be sold under certain specified conditions, as stated in lines 7 and 8, § 21, are the only features that directly interest consumers of power.

§ 28. A large proportion of the power in manufacturing establishments is used only 10 hours per day, so this investigation would not be complete if it did not include a presentation of the cost of steam power generated with large units for 10 hours per day. Such an estimate is made in Table III., the explanation of the items being given afterward as heretofore.

§ 29.

TABLE III.

SHOWING THE COST OF STEAM POWER ON THE BASIS OF GENERATING 20,000 H. P. CONTINUOUSLY FOR 10 HOURS PER DAY FOR 309 DAYS IN THE YEAR.

		Per cent of total cost.
1. Yearly cost of coal, § 30	$92,056	30.6
2. Estimated cost of labor, §31	27,198	9.1
3. Estimated cost of supplies and regular repairs, § 32	37,080	12.3
4. Estimated interest, insurance, taxes, and cost of renewal. § 33	144,000	48.0
5. Total	$300.334	100.0
which divided by 20,000 gives the following:		
6. Cost of steam power per H.P. per year on the basis of delivering 20,000 H. P. continuously for 10 hours per day for 309 days in the year	15.17	
7. Cost of steam power per H. P. per year on above basis if 5 per cent. of the original cost of plant be charged for dividends and $0.75 per H. P. added for general business expenses, § 18.....15.17 + 3.60 = 18.77; 18.77 + 0.75 =	19.52	
8. Cost of steam power per H. P. per year on above basis if 10 per cent. of the original cost of plant be charged for dividends, and $0.75 per H. P. added for general business expenses, § 19.....15.17 + 7.20 = 22.37; 22.37 + .75 =	23.12	

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§ 30. The yearly cost of coal, line 1, above, is obtained by computing the coal for 11 hours per day, for reasons explained in § 22 and making the calculations explained in the latter part of § 12 for 309 × 11 = 3399 hours in the year.

§ 31. The labor would be occupied 309 working days, and, say, one half the holidays, § 20. The cost of labor for 337 days of 10 hours or 3370 hours, at $5.40 per hour, § 13 = $18,198. Two assistant engineers could be dispensed with, compared with § 13, thus reducing the cost of superintendence to, say, $9,000 per year. The sum of these two quantities is written in line 2 of Table III.

§ 32. The cost of supplies and repairs is estimated at the rate of 0.6 mill per H. P. hour as per § 14, 20,000 × 3090 × $0.0006 = $38,080, as written in line 3, Table III.

§ 33. The amount written in line 4, Table III., is the same as for the two other cases. The cost of renewals should apparently be reduced as the machinery operates less hours, but the percentage allowed for renewals is very small and should be increased for the other cases rather than reduced for this. Moreover, renewals are made more frequently on account of new discoveries or changes in business than from the actual wearing out of the apparatus.

§ 34. The prices given in the lines 6, 7 and 8 of Table III., § 29, will best compare with those carried familiarly in the mind. The minimum cost derivable from the paper in TRANSACTIONS for 1893, above referred to, is for coal at $2.24 per ton and ten hours per day, $22.31 per H. P. per year. This should be compared with $18.77 in line 7, of Table III., as the previous calculations provided for 10 per cent. interest and dividends, as is provided in lines 4 and 7 jointly in Table III., but not for general business expenses. The difference is $3.54 per H. P., corresponding to a saving of 15.87 per cent. by generating the power on the larger scale.

§ 35. The quantities in the previous paper above mentioned were augmented here and there, so as by judgment to try and approximate the various losses incident to average practice, though insufficiently to show the results of such practice in some locations. The prices herein given, are as low as it would be safe to expect with very careful management of a very large plant. The comparatively small difference in result is due to the influence of the constant cost shown in line 4 of the several tables.

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It forms 26.3 per cent. of the total cost for 20,000 H. P. every hour in the year, Table I., § 8; 34 per cent. for variable power, 20,000 H. P. maximum, 12,760 H. P. average day and night, and rises to 48 per cent. for 20,000 H. P. during 10 hours of the ordinary working days in a year. The cost of coal is respectively 43.4 per cent. 37.3 per cent. and 30.6 per cent. of the total cost for the same three conditions. The fixed charges also increase greatly the cost of water power, as the writer has had occasion to call to the attention of parties engaged in these large hydraulic enterprises.

§ 36. It should be borne in mind that if water power or power derived from water be sold on a 24 hour basis, but can only be utilized during 10 hours per day, the cost of the water power direct or derived should be compared, not with the cost of steam power on a 24 hour basis in Tables I. or II., but with that of steam power on a 10 hour basis in Table III.

§ 37. It should also be borne in mind that all these estimates provide for fixed expenses, such as interest, insurance, taxes and cost of renewal, and that in comparing the prices above given with the cost of water power, similar fixed expenses should be added to the price of such power, based on the cost to the consumer of installing the water power or the mechanism through which the power is derived. For instance, manufacturers located on the canals of large water power companies necessarily build their own head and tail races and wheel-pits, and install the gates, screens, turbines and means of transmission for utilizing the power. This when well done, in many locations costs as much as to install a steam plant, so the fixed annual charges for this item alone would be $5.00 to $7.00 per H. P., which together with cost of labor and supplies, must be added to the cost to be paid for the water power in order to compare with the cost of steam power as presented in the tables of the writer.

§ 38. When power is electrically transmitted, the consumer is generally required to pay for the electric motor, the general means of transmission therefrom and some incidentals. The cost of this work, together with the portion of the building and even of the real estate occupied should be considered in the same way as has been done above, and at least 10 per cent. of such cost, together with actual costs of labor and supplies, added to the tendered price of net power delivered, in order to compare the cost of power obtained in this way with the cost of steam power

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shown in the various papers of the writer, which are written on the basis that a manufacturer should receive a profit on the money expended in plant as well as that expended in his business. If interest is left out in one case it should be in the other, and it is already included in the tables.

§ 39. The last column of the several tables, furnishes a ready means of eliminating either of the items of cost desired. For instance, in Table III., which is on a 10-hour basis, we find in line 4 that the "estimated interest, taxes and cost of renewal" is 48 per cent. of the total cost, which cost to the parties owning the power is in such table $15.17 per year, line 6. The cost of steam power per H. P. per year from large units for 10 hours per day, without considering the above items, is therefore only 0.52 x $15.17 = ... $7.89 which is the cost to be compared with the price of power from an external source when the items above referred to are excluded in each case as they are in the popular discussion of the subject The similar cost from the estimate in the TRANSACTIONS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS above referred to is $22.31, § 34, less (3.31 + 7.17) = 22.31 — 10.48 = ... $11.83, the difference $3.94 being due principally to the relative sizes of the plants considered in the two cases.

DR. EMERY continued:—Anticipating that inquiry will be made as to the cost of power from Niagara, at my request Mr. Foster has been kind enough to ascertain the facts. The Cataract Construction Company have offered undeveloped water power at this place for $10 per H. P. per year. They have also offered power delivered from the top of a shaft here for $13 per H. P. per year, and power delivered at the terminals of a dynamo here for $18 per H. P. per year. The power is evidently intended to be "24-hour power." For the first case, the lessees must evidently construct their own hydraulic work, involving the turbines and wheel-pits and hydraulic connections from the same to the head canal and the tail-race tunnel. For the second price, evidently the parties must pay the entire cost of transmission, starting from a vertical revolving shaft, upon which may be placed at their expense a dynamo or ordinary mechanical means of transmission. For the third price the parties must pay the cost of an electrical transmission starting with current delivered at the terminals of the dynamo.

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Discussion.

Prof. Wm. A. Anthony:—I would like to say just a word in regard to that last, in relation to what they propose to charge for power here. As I understand it that charge is based upon the maximum power that the party proposes to use, which puts a very different aspect upon the case from what it would have if it were power delivered by the meter. I have seen some of the contracts that are drawn up by the Cataract Company, and in them they state expressly that the charge is for the maximum power, and the amount of power is to be occasionally determined by some indicating instrument, and if at any time the maximum power used by the consumer exceeds the power for which he has contracted, then a new contract will be made on the basis of the largest amount of power he has used at any one time during the previous term. Now, as Dr. Crocker showed yesterday, the power that a man uses on an average is not more than 50 per cent. at most, of the maximum power that he uses. You will see that in paying for 200 H. P., for instance, at these rates, he really uses only about 100 H. P.; and in comparing what he would have to pay the Cataract Company for his power, you should compare it on that basis; that is, he is paying for 200 H. P., while if he were generating the power himself he would count 100 H. P. as the average. I suppose that in Dr. Emery's estimate of the cost of power, it would be the power actually used that would cost so much per annum, and in the case of a man using 100 H. P. actual, that estimate would show what it would cost him if he generated it for himself.

Dr. Crocker:—It is rather strange, but I was about to bring out a point similar to that spoken of by Prof. Anthony, only looked at in precisely the opposite way. I notice that Dr. Emery in the paper considers average power and not total power, that is, he divides by 12,760 and not by 20,000. In other words, he obtained the cost of actual power delivered, as Prof. Anthony has just said. Now, it seems to me that the ordinary manufacturer, developing his own power, does the opposite and divides by 20,000. In other words, he divides by the maximum and not by the actual power which he gets, and that is the way the very low figures for the cost of power generated in the ordinary factory are obtained, I think. The manufacturer knows in a general way the total cost of his power, although I think he often leaves out many items, and is apt to consider that all the cost of power is for coal, and he forgets incidental expenses, repairs, etc., that should be included, and which put together aggregate a large amount. But assuming that he does know what the total cost is, I think he usually divides by the total capacity of his engine, getting thereby a very low result per H. P. In other words, assuming that he has a 100 H. P. engine and that it cost him $3,000 a year. Now he is very apt to divide the $3,000 by the 100 H. P.

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and get the low price of $30 as the cost per horse power per year. As a matter of fact that engine, as Prof. Anthony says, probably has not been developing more than 50 H. P. on the average throughout the year. Therefore he should have divided by 50 and obtained the higher price of $60. I think the notion that power costs very little, is due partly to leaving out items of expense which should be included, but chiefly to dividing by the total power of an engine, or the nominal power, instead of by the actual power developed throughout the year. What Prof. Anthony says would imply that you should add a good deal to the $18.00 named in Dr. Emery's paper in order to compare it with the ordinary figures. My idea is that you should take the ordinary figures, and reduce them considerably before you could compare it with the $18.00. It amounts to the same thing, but it is not exactly the same idea. His remarks imply that the ordinary manufacturer is accustomed to consider the actual power developed, in which I do not fully agree with him.

PROF. ANTHONY:—My remarks were based upon two or three factories that I happened to know of, where the parties keep a pretty good record of the power that they are using, by indicator diagrams taken occasionally along through the year. They take diagrams perhaps every day, and keep a sort of average in that way of the power that they use during the year, and divide by that average power, as indicated by those diagrams. That is the way the price has been obtained in three or four manufacturing establishments of which I happen to know.

THE SECRETARY:—While I am not altogether familiar with the subject under discussion, there is one thing that occurs to me in connection with our various publications in the TRANSACTIONS, and that is that there has never been any reference to the use of mechanical stokers. In talking with some of the European engineers, I have been told that they are quite commonly used over there; but so far as I know there has never been any reference to the advantage or the disadvantage of using them, or as to their practicability in this work, where the tendency is toward the greatest economy; and it appears to me that on this occasion it might be well to make some reference to that in connection with this paper by some of the gentlemen who are familiar with the subject.

MR. OBERLIN SMITH:—I want to ask the question whether the price which is mentioned for power from the Cataract Company is based on a minimum of 20,000 H. P., or whether they will sell smaller quantities at those same rates; because, if they will, the comparison would not be fair with a 20,000 H. P. steam engine. A small unit of steam power, say 1,000 or 2,000, would, of course, cost considerably higher than Dr. Emery's estimate for 20,000; so that we ought to know, in discussing this comparative power of water and steam, whether we are talking about the same sized unit.

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DR. EMERY:—It seems necessary to answer the questions so far raised at once. The paper under discussion refers to my previous INSTITUTE paper on the same subject which was based on 500 H. P. units. Questions as to the cost of the power with smaller units, or in engines of different kinds are not raised in the present paper, but anticipating that they would be in the discussion, I have ascertained that, using 500 H. P. units operated 10 hours per day on working days, for coal at $2.24 per ton, delivered in front of the boilers as in the present paper, but with other conditions the same as in the former paper, the cost of steam power would be approximately as follows:

Non-condensing engine	$29.90	per H. P. per year.
Condensing engine	23.81	" " " "
Compound engine	22.86	" " " "
Triple compound engine	22.31	" " " "

The last price is the only one stated in the present paper and is in section 34 compared with the corresponding cost with large units, viz: $18.77 per H. P. per year (line 7, Table III.,) the difference, $3.54 per H. P., corresponding to a saving of 15.87 per cent. by generating the power on the larger scale. It will be recollected that in the former paper, by assuming different prices for the different engines, the increase of the interest practically balanced the saving in coal, so that there was very little difference between the better classes of engines of different kinds when all the costs were considered. The final results have proven to be remarkably near those that have been obtained in actual practice by others who have communicated with me. In that paper the extensions were not made on the basis of the best experimental results, but allowances were included which augmented the costs so as to approximate actual practical conditions. In the present paper the extensions were made on the basis of the lowest quantities derived from experiment, which it is considered can be repeated in practice under careful management.

MR. OBERLIN SMITH:—Can you tell me what the smallest amount of power is that the Cataract Company will furnish at the prices that were mentioned?

DR. EMERY:—I do not know. I anticipated that general questions as to the cost of power here would arise and was therefore prepared to answer them. There are gentlemen connected with the company here who may be happy to give details of the kind requested.

MR. SMITH:—In order to have a definite unit of a smaller size I will ask the gentlemen directly, what they would charge for 1,000 H. P.—about what increase over the figures given in this paper? I will ask what per cent. will have to be added if they take on a basis of 1,000 instead of 20,000; that is, roughly speaking, how much more would it cost?

DR. EMERY:—For steam power, comparing the prices in the

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present and former papers, the difference is only $3.54 per H. P. For engines of different kinds, the difference will be increased by amounts corresponding to the increase of yearly cost which I have already read. As the discussion appears to drift toward general questions instead of being confined to the special one considered in the paper, I will write the costs of power for engines of different kinds on the blackboard with the permission of the President.

MR. SMITH:—In the meanwhile, will any one in the room say whether the Cataract Company proposes to furnish at the price mentioned as small a quantity as 1,000 H. P., or, if not, about how much more it would cost in that small quantity?

MR. JOSEPH WETZLER:—I believe the Carborundum Company has closed a contract for 1,000 H. P. to begin with.

MR. PETER WRIGHT:—The Carborundum Company pays $20,000, I understand, and the prices quoted, $10, $13 and $18, are for a minimum of 10,000 H. P. That is my recollection from an article in the *Electrical World* a few months ago.

MR. SMITH:—Then on this 1,000 H. P. they pay about $20 instead of $18, which they would have to pay for a larger amount, is that the idea?

MR. WRIGHT:—That is my understanding.

MR. SMITH:—Then we appear to be working on a basis in this locality of 1,000 H. P. at $20. That is, delivered at the Cataract Company's house, is it not, at the dynamo terminals? Now we have something to compare with steam power, when we find out what that will cost here in units of 1,000 H. P.

MR. WRIGHT:—In looking over these figures of Dr. Emery's, I am a little surprised that there is no provision made for depreciation. I suppose that Dr. Emery did not overlook that, but I am a little surprised that no provision is made. I have made a simple calculation here, allowing for depreciation four per cent. on a plant costing practically a million and a half. The added cost would be $2.88 per H. P. per annum, and I would like to ask Dr. Emery why that amount is not fair to be added. It seems to me that in an undertaking of this magnitude it would be only wise business policy, to say the least, to make some provision for depreciation, and four per cent. allowance would be about right, I think.

DR. EMERY:—This discussion is covering so large a field that with your permission, Mr. President, I will answer these questions as they arise. The depreciation is already considered in the tables given in the paper, but under a different name; it is called "cost of renewal." There are two ways of treating the matter. One is to depreciate the property on the books every year, and the other is to consider that a certain amount is withdrawn from profits and put at interest in a sinking fund to renew the plant at the end of a definite period. If we depreciate four

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per cent. of the original cost yearly, such cost will be wiped out entirely in 25 years. If the depreciation is four per cent. of the cost shown on the books for the previous year, the reduction will be much slower. If, however, four per cent. of the original cost be put at interest yearly, the resulting sinking fund will equal the original cost in 15½ years. It will be seen, therefore, that the method adopted makes a great difference. It is not necessary to deposit four per cent. of original cost yearly for renewals; three per cent. is ample even under modern conditions, where plants are changed constantly on account of new conditions, or change of business, since at six per cent. it corresponds to renewal in 18½ years, and at five per cent. in 19½ years.

MR. OBERLIN SMITH:—The cost given for the triple compound engine is, I presume, for a 1,000 unit?

DR. EMERY:—It was 500 H. P. or multiples of that sum, and does not change very much, so that that is near enough for your calculation.

MR. SMITH:—$22.31 then, covers everything? That is, it buys coal here and pays interest, depreciation, incidental expenses and everything else, so they could actually farm out this power at $22.31 if they had that given engine——

DR. EMERY:—I will ask you to yield one second, if you please. That is on a 10-hour basis. I intended to mention that. It is a very important consideration. As you will see, those prices are not as high as they would be, on a basis of 24 hours, but most of our power is run for 10 hours, and the figures given above are on that basis.

MR. SMITH:—Assuming that a concern could only run 10 hours, as most factories can placed here,—assuming that they are a little way off from the terminals of the dynamos where the loss on the line would only be small, that they have got to put in the transformers at their own expense and get the power in shape to use, the price would be about $20.00; so that on the 10-hour basis it would seem as if it cost the same here on a 1,000 H. P. unit to buy this water power from the Cataract Company, or to have the steam power. But on the large unit, the water power would very likely be somewhat cheaper, the electric water power, or whatever you call it; therefore, on a 24 or a 15-hour basis, should a factory want to run that long in a day, the water would seem to be the cheaper, because you have to pay just as much for 10 hours water as you do for 24, as I understand it.

DR. EMERY:—It seems necessary to recall attention to the fact that if power be furnished a manufacturer at the terminal of a dynamo, he must run his own line to the motor, put in the motor and connect it at his own expense in a building belonging to himself, and then put a man in charge of it. The motor, with a mere local line and other work required will cost, say, $30.00 per H. P., which at 10 per cent. makes $3.00 a year fixed expenses.

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The man's time cannot be neglected, so on this basis $3.00 per H. P. per year, plus the whole or a portion of the man's time must be added to the cost of power delivered electrically in order to compere the same with the cost of steam power as given in this paper. This is not all, for if the power is sold at electrical terminals, miles away, interest on the cost of the main transmission line and a charge for transmission losses must also be added.

MR. SMITH:—I should say that that is a very high estimate; to add half, making it $30.00 instead of $20 per year—so simple a machine as a motor is, and so little attention as it requires and so small as the repairs are.

DR. CROCKER:—I think that Dr. Emery's last statement is not exactly fair to the electrical system. The object of my paper this morning was, to show that given a steam engine in a factory, the cheapest and best way to get that power to the machines was to put in a dynamo, conductors and motor. Consequently we have to compare the steam engine in the man's factory with the electrical power in the Niagara power house. That, as I understand it, is the true comparison. Now the question is,—How shall we get that power to the machine tools in the two cases? That is too difficult a problem to go into here, but it was certainly the object of my paper, and, so far as I have heard, there were no exceptions taken to the general conclusion that the best way to get the power to the machine tools was to turn it into electricity and turn it back again into mechanical power; and in this particular case we have an advantage over the case considered by me, because in the latter we have to supply a dynamo also. Here we have the electrical energy given to us, and we would simply have to supply the line wires and motor, the factory presumably being located near to the power house, or at a reasonable distance, for 2,000 volts pressure. It would probably be necessary to introduce step-down transformers, as we would not be likely to use 2,000 volts in the motors at the factory. But that item of expense would not be large. I do not think it is fair to consider that the simple steam engine cost is the total cost of the power for driving factories. The system of distribution must be included.

DR. EMERY:—These tables are not yet fully understood. The statements made by Dr. Crocker are not disputed, but the interest on the cost of the steam engine is already in the price given for steam power; 10 per cent. of the original cost being added in line 4 of each table for interest, insurance, taxes and cost of renewal. Therefore, there must be added to the price that is charged for water power 10 per cent. of what it costs to utilize it. If the electric current is received from a local company, it may, as stated, possibly be utilized for a local outlay of $30.00 per H. P., when $3.00 per H. P. per year should be added to the price of the power and more or less, as the cost is greater or less, and to this should be added the cost of labor as explained,

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also the cost of repairs and supplies, which I omitted to mention a moment ago, though considered in the tables. If, however, the price for power is fixed at, say, $18.00 at electrical terminals miles away from the city where the power is to be utilized, the cost of a general electric transmission must also be considered, and as this would be too great to be undertaken by small consumers, it must necessarily be constructed by a company which must add its own interest, repairs, maintenance and profit, thus increasing the cost to the consumer correspondingly.

MR. SMITH:—I think, Mr. President, we are trying to compare entirely different things which depend upon how you look at them. Now if we assume, with Dr. Crocker, that we are going to run a factory or a shop with motors all over it, as in all probability will often be the case in the future, then the electric power will have the advantage, because, as he says, Dr. Emery will have to add his dynamo, short line wires and the motors in with his steam plant. But if the calculation is based rather upon the old-fashioned way of running, with a lot of shafting and belts all over the mill, in such case Dr. Emery would be right. So before we know which is right we must know which system we are going to run the mill on. As a practical matter this power delivered here in factories will in some cases be used electrically, like it is in the Reduction Works, where they do not want any rotary motion; but where it is wanted as rotary motion there is no doubt, in this electrical age, that much of the machinery would be run, individually or in groups, by motors, and therefore we would have to have them anyway in addition to the steam engine; so it still gives some advantage to electric power. The calculation I made roughly just now, bringing them about equal for a 10-hour day, only allowed the cost of the short line, which would not be much (and the loss in it would not be much), and the cost of the transformers to get the big voltage down, but I did not allow for the motors scattered around the factory, and it is very proper to leave them out, because in a modern system we would have to have them anyhow, even with a steam engine.

MR. LEWIS B. STILLWELL:—I should like to ask Dr. Emery a question in regard to the estimate on page 365, Table II in which the "cost of steam power per H. P. per year on basis of "delivering 20,000 H. P. maximum and an average of 12,760 H. P. "for every day in the year" is calculated to be $33.14. Is there any allowance in that for the cost of attendance upon and maintenance of electrical machinery, which would be necessary to put such a plant upon a fair basis of comparison with the plant of the Cataract Construction Co. here at Niagara Falls, for example?

DR. EMERY:—There is no such estimate as that, Mr. President. There is an estimate for the cost of an engine to make the wheels go around which is to be compared with that of an electric motor to make the wheels go around. If, as it has been urged here, the cost of a motor is not to be charged in one case

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then the cost of an engine should not be charged in the other, and in the case previously referred to it is necessary to make the comparison as in § 39, not with steam power at $22.31, but with such power at $11.38. We start in both cases with a shaft in revolution either with a steam engine or with power electrically transmitted.

MR. STILLWELL:—That replies to my question, and states the point to which I wish to call attention. In the paper which Dr. Emery read a year or two ago, I think the estimate of the cost of steam power was based upon the assumption that we were to drive a line shaft, and apply to that line shaft 500 H. P. It ought to be noted that when this is taken as the basis of comparison we should compare the cost of the hydraulic machinery in the electric-hydraulic plant, and stop at the end of the hydraulic machinery. It is not fair to the electric-hydraulic plant to take the 500 H. P. unit from the engine on the engine shaft, or a 20,000 H. P. unit on the line shaft, and compare this with electric power delivered at the terminals of a generator. Dr. Emery explains that the 20,000 H. P. is meant to make the wheels go around—the ordinary wheels which we have in factories and mills. It seems to me it ought to be brought out clearly that, in order to make this comparison exactly fair, we should add to the cost of the steam power, as we calculate it, the additional cost representing the interest on the investment in the electric generators, and attendance, depreciation, and other charges properly chargeable against the electric plant. In order to bring the 20,000 H. P. steam plant to a basis fairly comparable with the electric plant in the power house of the Cataract Construction Company to-day you would have to purchase generators. You cannot take 20,000 H. P. on a shaft and compare it with 20,000 H. P. at the terminals of a generator, ready to be transmitted and distributed.

MR. B. J. ARNOLD:—The point brought out by the last speaker, I think, is a very essential distinction. The actual work we have to do with power in large cities is such that it is necessarily divided into small quantities or units. We have very few power users who will require power in 1,000 H. P. units, so that the real comparison to be made is between the cost of power delivered at the work by the transmission plant in, say, 100 H. P. units, or even less, and the cost of power in similar quantities produced by steam. Now power in these quantities costs in our best steam plants to-day about one cent per H. P. hour delivered on the engine shaft. Reducing this to its equivalent in electrical energy, we get a kilowatt hour on the switchboard ready for distribution to our small motors for about one and one-third cents in the larger plants and not over one and three-quarter cents in the smaller ones. It seems then that if we can buy power produced by this transmission plant delivered at the terminals of the small motors in our individual factory machines for less than one and one-third cents per kilowatt hour, that it would pay us to buy it. Unless

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we can do this, we can put in a steam plant and operate our factories cheaper by steam.

One point brought out by Dr. Emery's paper is the necessity of operating large steam units if we are going to put in a central station to distribute power. The cost of labor is reduced very largely, as the size of the unit increases. He has mentioned the fact that it would be desirable to connect one or more units in some manner so that a large steam engine might operate a number of electrical units. I think this is very desirable, and if the shafting could be eliminated, it would reduce the cost of labor to probably 20 per cent. in a 5,000 H. P. station over what it would be if we had a large number of small steam engines to operate. Another thing which I understand from the contracts that the Cataract Construction Company are making with consumers is, that they require the consumer to contract and pay for a certain amount of power, and not to exceed that quantity. This has been found very objectionable in city practice. In other words, if the consumer exceeds for a short time the total amount of power his contract calls for, he is violating his contract and is compelled to make a new contract covering the increased amount, even though he does not expect to use it. The power should be put upon a meter basis, or upon some dynamometer basis, so that he would pay for the actual power used. I think any power user will concede this, but the difficulty is to get the power companies to execute a contract on this basis.

As to the question of mechanical stokers, which was mentioned by the Secretary. I have had more or less to do with this class of work, and while I find most of the mechanical stoker and patent furnace companies willing to guarantee to evaporate 1,000 pounds of water for from 11 to 13 cents, by the use of bituminous slack coal, which is about eight cents less than the ordinary boilers evaporate water for, when using bitumious run-of-mine coal, I find that the cost of maintaining these stokers and their appurtenances almost equals the saving in fuel in small plants, so that there is but very little object in using them, except in the large power stations where, owing to the great distance that the coal has to be handled, mechanical coal conveying plants can be put in, which will deliver the fuel directly into the stokers, thereby effecting a large saving in labor and making the stokers more economical and desirable than hand firing.

MR. HARRY ALEXANDER:—Mr. Stillwell touched upon a point that until then I was totally at sea about. If, as Dr. Emery mentions, the power is to be rented at the wheels, how, in small parcels, is this power going to be transmitted? If it has to be transmitted to generators, and from those on to motors, including the line and the motors as well, I do not think it a fair comparison at all. If the Cataract Construction Company is willing to rent at $10 per H. P. at the dynamo terminals, and, as Dr. Emery mentions, for $11.83 per H. P. where the wheels turn

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around, the advantage lies immediately, as far as the price per H. P. is concerned, with the electric power. That is, you have only to construct your line, furnish your transformers and your motor, whereas in small parcels with steam transmission you would have to hitch on to the line in whatever manner suggested itself, which would include belting to the mechanical shafting and the dynamo, etc. This dynamo naturally would have to be placed at the power house. Now the question arises,—Is there room for that? If there is room, has that room been figured on? The matter that I was at sea upon was, how that power was to be transmitted, and if it was to be transmitted by mechanical power, as I thought, why then this question arises of belting to the shafting and the dynamo and the room for the dynamo and the increase in the size of the building, etc. The cost of that has, I think, been left out of Dr. Emery's calculations.

DR. EMERY:—Again I have to make an explanation, as the discussion has drifted to questions not raised in the paper. I have many times been asked to work out the theoretical cost of steam power derived from large units. I anticipated that questions would arise in the discussion as to smaller units of power, and have therefore placed upon the blackboard some results taken from the former paper, but the units even in that case are too large to cover some of the ground discussed here. Mr. Arnold has hit the nail closely on the head by the statement that in ordinary practice a horse-power hour costs about one cent. That rate for a year of 3,090 hours would make $30.90 a year, and looking at the figures on the blackboard we find that the price given for non-condensing engines in my previous paper is $29.90 per year for 500 H. P. engines, which is too low for small engines and conservative for large ones This is a little less than one cent per H. P. per hour, and for more economical engines the cost would be a little less than $\frac{8}{10}$ of a cent. All the expenses incident to 75 H. P. developed in a non-condensing engine ought to be obtained for $1\frac{1}{4}$ cents per H. P. per hour, and this cost would run down to $\frac{8}{10}$ of a cent with larger powers and better engines.

We are now prepared to discuss the general question: For what price can be installed and operated a steam engine for an establishment requiring 75 H. P. and upward, and what is the yearly cost of such power in comparison with power derived from electrical transmission? As stated, the cost of steam power in plants not smaller than stated would vary from $1\frac{1}{4}$ down to $\frac{8}{10}$ cent per H. P. per hour, which includes everything required to make the shaft revolve. If lights are required in the building, a dynamo must be used, but ordinarily only for that purpose. For power delivered electrically, as Mr. Arnold has very clearly stated, such power must be transmitted from the dynamo here, for instance, to the point at which it is to be used, in Buffalo or elsewhere, and in general sent out again to a motor in an establishment where the power is to be used, and the net power must

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be delivered for $1\frac{1}{2}$ cents per kilowatt hour in order to compete with steam for power. The more exact figures given above are equivalent to $1\frac{2}{3}$ cents for kilowatt per hour for the higher limit, and this price falls to $1\frac{1}{10}$ cents for better engines available from 100 H. P. and upward. For lighting and power in small quantities, more may be charged, say about 2 cents. The greater convenience of power derived from electricity would give some advantage, but the cost must be balanced in the way I have already several times pointed out. I think I have made the matter clear, but will be happy to go over it again if desired.

MR. ALEXANDER:—I would like to put this question to Dr. Emery: In what manner is it proposed, even for short or long distances, to transmit this mechanical power for industrial and manufacturing uses? This is a point I do not as yet fully understand.

DR. EMERY:—I propose to erect a steam engine and boiler directly in the building where the power is required.

MR. ALEXANDER:—Then the idea of comparison is only to large units, not units of 1,000 H. P.?

DR. EMERY:—The paper refers to large units, but small ones are now being discussed. The question is, whether we shall put in steam plants where the work is to be done, or an electric plant to utilize electric current transmitted through a wire.

MR OBERLIN SMITH:—We all, I think, have a great deal of confidence in Dr. Emery's calculations on steam power, and I should freely accept them rather than work them out myself. I have no criticism to make on the paper itself whatever, but in making this comparison, the question arises,—are we right in comparing so large a unit as 20,000 H. P.?—because if we get this great plant Dr. Emery has considered, we have the wheel going around, but who of us here knows what to do with a revolving shaft that has 20,000 H. P. stored in it? How are we going to distribute it for ordinary operations? How many belts, pulleys, shafts and journals are required to distribute it and divide it up, as Mr. Arnold speaks of? For ordinary purposes, outside of driving a city full of cars, or something of that kind, we want this power split up, and we have to allow for the expense of getting a steam power mechanically and distributing it among our shafts and belts. And then it is not the question of starting a great plant here to rent out power generated by steam. We would have to have special means of transmission to neighboring factories to get rid of 20,000 H. P.—cables, very long shafts, or someting of the sort, and here is where the electric power seems to have the greatest advantage, as it has an infinite capacity for being divided up as much as we choose. When we have 20,000 H. P. at the terminal of the generators, we can run an ordinary wire, or cable of wires out, with hardly any expense for short distances, and divide them up in as many branches as we like; so that really, after all, this discussion ought to have

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taken place on a much smaller unit, on perhaps 100 H. P., as the factories in question would, under ordinary circumstances, naturally, have their own engines, one 500, another 100, another 50, and so on. We ought, therefore, to take a small unit for comparison, thus bringing the steam power expense higher. And then the question comes up,—how is the power going to be used in the factory? If, as I said before, we want shafting and belting and the old-fashioned methods generally, then steam may be nearly as cheap; but if we want the new-fashioned method of having motors, then we would have to have them with the steam engine, and the electrical power seems to have the advantage. I suppose the fact is that the Cataract people will really put this price that we are talking about just a little lower than steam, so as to tempt people to come. It does not need to be a great deal lower, naturally, as a merely commercial matter which regulates itself.

MR. STILLWELL:—It seems to me that Dr. Emery has given us all we can ask in the way of estimates on the cost of steam power, and has now stated clearly what is intended by his estimates. The discussion has rather drifted away from the paper. His paper last year made an estimate of the cost of steam power on the shaft in units of 500 H. P. That is a valuable estimate. I am sure that electrical engineers and others who have had occasion to figure on the cost of power have used it many times; but in using it, some care has to be taken to be sure that we are making the proper kind of comparison. If we take the 500 H. P. delivered to a shaft in Buffalo, we should obviously in making the comparison take care to include every item in the cost of a hydraulic and electric plant necessary to deliver at a line shaft located in Buffalo the same amount of power. Now the paper to-night makes a calculation of the cost of a steam plant to develop 20,000 H. P. This is more than we have occasion to use in one unit, except in the central station. All that we have to do in using that calculation as a basis of comparison with the cost of hydraulic and electric transmission is to be sure that we compare with it only the cost of the hydraulic machinery ready to deliver to the electrical machinery, or any other machinery, 20,000 H. P. I am sure that Dr. Emery's calculations have been very valuable and useful. The results may or may not be realized. They at least indicate an ideal toward which steam practice is tending. The results as they are stated, taken as an ideal, are, I think, encouraging to hydraulic and electric transmission in general. The estimate to which I first referred (viz.:—$33.14 per H. P. per year, on an average of nearly 13,000 H. P. in a 20,000 H. P. maximum), is one against which almost any hydraulic plant can certainly compete. If you add to this estimate the cost of the electrical plant necessary to put this 20,000 H. P. steam plant on the same basis as the hydraulic-electric plant ready for transmission, the figures will be raised considerably, and I am very sure that the electric and hydraulic

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plants, assuming that high load factor, can in general compete successfully.

Mr. Nelson W. Perry:—It seems to me that one feature of this question has not been touched upon to-night. That is, suppose we had a project to establish a plant ultimately to be expanded to a given larger capacity, would it pay us to take a water power and through that water power employ that capacity, or would it be more economical for us to do it by steam, assuming certain conditions of cost of coal and other necessaries? Now, in a water power plant, it is usually necessary to develop in the beginning a very much larger proportion of its utmost capacity than there is any immediate demand for. Take the plant here. It was necessary, in order that a single horse-power should be available, to tap the river above the Falls by means of a tunnel. At the start of any enterprise of this kind we may be sure of an immediate demand for but a very small portion of the maximum capacity. We know that in a given water power where there are, say, 10,000 H. P. available, we can count upon an immediate sale of only, say, 1,000 H. P. We have to develop that 10,000 H. B., however. Dr. Emery has called attention to the great influence upon cost of the fixed charges. While we are selling that 1,000 H. P. with an available 10,000 H. P., we are paying fixed charges on 10,000 and charging only for 1,000 H. P. If on the other hand we have coal and are projecting a plant of equal size, we put in, say, two 500 H. P. units to supply the existing demand and pay fixed charges in the beginning only on that, and then when the demand increased we would put in another unit, and so on, so that we would have an output of nearly all our plant from the time we started. I think that among engineers that point is not so often overlooked, but among those who have not given the subject attention it is overlooked a great deal. They assume that where they have a 10,000 H. P. water power, and it costs so much to develop, interest, etc., that the cost per H. P. to them is that cost divided by 10,000, whereas it is that cost divided by 1,000. Now, in a growing project of that kind, where it is necessary to make a very large investment with the expectancy of an increasing demand for the output, it must be uneconomical at first to start a water power. Under most conditions a steam plant would be much more economical, for the reason that we can increase it as the demand increases, and pay fixed charges only on a plant actually earning to nearly its fullest capacity.

Allan V. Garratt, of Boston:—I am inclined to take exception to what the last speaker has said, for this reason,—if we start out to build a 10,000 H. P. hydraulic plant, the conditions are not often the same as we find here at Niagara Falls. I could quote perhaps a dozen cases of plants in the far West, where peoples' ideas are apt to be large, and where they wish to lay out for a comparatively large plant ultimately, but realize quite fully that the present demands for power will be small. It is self-evident

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that if you wish to come out with a very large plant at some time which you hope will arrive in the future, it is not necessary to build the whole plant on the 10,000 H. P. basis. There is a certain portion of your construction that may be necessary to be completed from the first, but those water powers as a rule are avoided by investors, which make this necessary to any large degree, and such construction can usually be put in which will take care of such a load as can be obtained in the immediate future, without making such an extortionately great investment. On the other hand, it is undoubtedly true that in almost any water power plant the first development must be larger than in a steam plant. That is undoubtedly true. I never have known a case to be otherwise. But the difference is not so great in favor of the steam plant as the last speaker would seem to intimate. Now, under the comparatively high heads which obtain throughout a large portion of the United States, especially the growing portions of the United States, as for instance on the eastern slopes of the Rocky Mountains, and on the western slopes of the Sierra Nevada, and the Cascade ranges, we find water powers tumbling down through deep canyons in such a way that you can take off a portion of that water and carry it down through a steel flume, which is a common practice in that country, and investment in wheels and heavy masonry at the base, and all that sort of thing is carefully looked after at the start, and they go right on with the development in proportion to the output of the plant. It is not necessary in the majority of cases to put in an enormous construction at the start which must not be touched while your plant is being loaded up to the maximum point which you intend to reach. So that the investment can in a very great number of cases be kept very small, and the investment increased as the earning capacity of the plant increases. And you will find if you look over the history of water power development in the United States, you will find that water power properties, which require enormous investments in the start, have not been touched unless it is seen that a very large earning capacity can be gotten from them at present. But let us take for example, well, the Rainbow Falls across the Missouri River, which comes into my mind at present. There is naturally a very good water power, capable of giving, I should think, in the natural effect of the river at that point, perhaps, 50,000 H. P., as a rough estimate, and at the present time they are using about a twentieth of that. Now the construction at that point is such that it is just right, it is thoroughly adapted to what they want at the present time and in the immediate future, and is such that they can can keep on developing it, just as when people build a steam plant and so arrange it that the steam plant can be increased up to any load they are going to have, without making an extortionate investment at the beginning. So I think it is hardly fair to the water power to lay it down as a broad and fundamental fact that when you

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start out with the ultimate intention of developing power in very large amounts, your investment must be for the ultimate output of your plant from the very start, and that if you intend to have 1,000 H. P. developed at once, that you must make the price of the 1,000 H. P. you are going to sell on the basis of the total fixed charges on 10,000 H. P., because it is not anything of the kind. Neither is it fair, of course, to say that you divide the fixed charges on 10,000 H. P. by 10, and call that the price on 1,000. The history of water power plants, so far as my experience has gone, has led me to see that the operating expense and fixed charges get less and less as you go up in size of plant, until it finally reaches the minimum. This is not so absolutely unreasonably as one might be led to suppose, and on the other hand we know that very many steam plants are so poorly laid out, that you do not get the proportionate decrease in fixed charges and operating expenses as the load increases.

DR. EMERY :—The principal points have been so thoroughly considered in detail, that there is little to say in closing. The most important question yet remaining seems to be that raised by Dr. Crocker and Mr. Stillwell, to the general effect that the fixed expenses due to an electric transmission plant should be added to those of the steam plant, for the reason that 20,000 H. P. could not be utilized at any one place, and that a means of transmission and sub-division is necessary. This is true in regard to 20,000 H. P, but not true of moderate sized plants where 25 to 100 H. P. and upward is required. Dr. Crocker urges that an electrical system is the cheapest way of distributing power even from a shop engine to the various tools, but it would seem extreme to urge this system for plants of 100 H. P. and less, particularly for those already established. Water power transmitted electrically to large cities will for a considerable time be principally required as a substitute for steam power already installed. In such cases evidently the cost of the installation of the electric plant, together with its operating expenses, should be added to the cost for which the power is delivered. Even if it is desirable to employ largely the system of electric motors operating individual tools, or clusters of tools, as referred to in Dr. Crocker's paper on the subject, this is a question of shop economy which does not affect that of bringing the power to the shop. The former, with old plants, has nothing to do with the case, and with new installations the electric plant can for moderate powers at least be charged to shop transmission and not to the power. In the majority of cases, therefore, the only logical method of comparison is to start with a revolving shaft. Without disputing the broad proposition of Mr. Stillwell as well as Dr. Crocker, that power from a large steam plant must have means of transmission to the several kinds of work in detail, this is also true of large steam plants already installed. The units of the 20,000 H. P. plant are only 2,500 to 5,000 H. P., which are in frequent use, and the elaborate lines of

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shafting, gearing, belting, etc., from such units to rolling mills, flouring mills, cotton manufactories, etc., are necessary and expensive but form a part of the internal transmission, not that of bringing the power to the works. An electrical transmission in the factory is only a substitute for this, and should be charged in the same way. We grant, however, that there is much in the suggestion, as applied to a very large steam plant designed to distribute light and power in opposition, we may suppose, to proposed distributions of power derived from water, but this is not the question at issue. In developing a water power, the question is how such power can be most economically transmitted and distributed, and the same question exactly would arise in relation to a large steam plant. From our present lights, the natural answer is,—put the water or steam power into electric energy as soon as possible, and this will be available at the points of transmission both for lighting and power purposes by the use of proper apparatus. The cost of such transmission and distribution might be so great as not to warrant carrying out the enterprise either for water power or for steam power. The question may be asked, then: What is the value of an estimate on a 20,000 H. P. basis as given in the paper; steam plants on land are unknown that require such a power locally; it is only a steamship that requires it? In response I may say that, curiously enough, the popular mind wanted what may be termed a bottom price for comparison. I have been asked to make such an estimate by many. I was asked to make it by the general officers of the Cataract Construction Company. They wished to know the cost of power on this large scale developed in a plant in the outskirts of Buffalo. I responded that I did not think that was what they wished to know, and asked permission to tell them what my views were, and finally was requested to do so. I trust there is no breach of confidence in making this statement, but will not try to remember my reply. I, however, say now that *the basis of comparison seems to me to be the relative cost of power delivered in desired quantities to the several consumers as compared with the cost of steam power on the premises.* Mr. Foster has since examined the subject for the company. His investigations show that steam power costs in Buffalo much more even than stated in my original paper in 1893, which at the time was considered unnecessarily conservative by many parties. I do not think the details of Mr. Foster's determination have ever been submitted for criticism, but if the results are accepted, the parties attempting a solution of the problem should consider what the results would be if the manufacturers of Buffalo should adopt means for securing economy in steam power.

Let us examine what this discussion has developed in this line. If one H. P. delivered at the terminals of a dynamo here for $18 per year can only be utilized 10 hours per day, or, say roughly, 3,000 hours in the year, the power delivered at the dynamo

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terminals here will cost $\frac{6}{10}$ of a cent per H. P. per hour. Some power will be sold out of business hours, but the maximum power must be charged for all the time, so with a low power factor, as is probable, the average cost cannot be greatly varied. By Mr. Arnold's short rule, modified in both directions by the figures I have given, the power should on the average be delivered by steam engines in Buffalo, with all charges of interest on plant, attendance, repairs and supplies added, for about one cent per H. P. per hour. Upon this statement of the problem, who will undertake to "bell the cat," put in the transmission line, connect with the several stations there, or build new ones, send out this power locally, furnish the motors and connections and deliver power to the several consumers at these prices? Can it be done by any other parties than those who wish to receive $18 per H. P. at the dynamo terminals here?

The President announced the appointment of the following members as a Committee on Resolutions: B. F. Thomas of Columbus, O.; B. J. Arnold of Chicago, and W. J. Hammer of New York.

[Recess until 10 A.M.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Twelfth General Meeting.

Niagara Falls, N. Y., June 27th.—Morning Session.

President Duncan called the meeting to order and announced that Dr. Emery would speak briefly in continuation of the discussion on his paper of last evening.

Dr. Emery:—In conversation with a number of those present it has appeared that it would be of interest to state a case where electrical transmission was *not* the best means to employ. It was hardly applicable in the discussion of Dr. Crocker's paper, so I will now give a brief outline of the case as a continuation of the discussion of last evening. I was recently called in consultation in regard to a steam plant in the refineries of one of the oil companies in which there were burned, in four boiler houses, about 64,000 tons of coal a year. There was a large number of pumps for transferring the oil, large and small steam engines, and steam and hydraulic pumps in various buildings, so that steam from about 3,000 boiler horse-power was delivered for power, independent of which more than this amount of boiler power was required for heating purposes. The executive officers were experts in their line, and had studied out a large variety of ways for obtaining economy in fuel. They had thought of the plan of taking out the steam pumps, and putting in power pumps operated by economical engines, and exhaust heating was to some extent used, but as a general system, had not received direct attention. Finally in consultation with the electrical people they became interested in a large electric transmission system. It was proposed to put a multiphase generating plant of about 3,000 kilowatts capacity near one of the boiler stations, where high pressure steam could be secured to operate engine dynamos and transmit power electrically through an underground line and multiphase motors in different parts of the buildings and grounds, the lighting being

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incidentally done by the same plant; the steam for heating, however, to be supplied by the other boilers. The change would cost a considerable sum of money, and my advice being asked professionally, I saw at once it was not a case where a general system of electric transmission was applicable, but advised raising the back pressure on the uneconomical engines, and distributing exhaust steam to the several heating points, meanwhile providing to put in a small multiphase plant of 75 kilowatts to replace three smaller electric lighting plants, and operate a few multiphase motors at different parts of the yard where the steam pipes were very long and much exposed. The results at last accounts, before the work was fully completed, was that about one-third of the boilers were shut down and fully one-half of the coal was being saved or at the rate of about 32,000 tons per year. This case is simply an illustration of the fact that electricity is not a "cure-all." It has its desirable features, but sometimes there are other ways by which the results desired can be accomplished much more satisfactorily. The question may be asked what the relative saving in fuel would have been to carry out the first plan, using large economical units to generate the electrical energy, but running extra boilers to do the heating. The difficulty with this plan was, that the heating was so large a portion of the work, that by generating steam and running it through the engines first, the exhaust steam would develop the power for practically little more cost than the thermal losses in the transmission of steam. In other words, the engine dynamos, the transmission plant and motors should, in order to compete with steam, furnish the power with a quantity of steam sufficiently less than that *condensed* in the steam transmission plant, to pay the interest on the investment in the electric plant.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th, 1895. President Duncan in the Chair.

THE CAUSE OF DEATH IN ELECTRIC SHOCK.

A. M. BLEILE, M. D.,
Prof. Physiology, Ohio State University.

The work here given was undertaken with a view to elucidating the effects of larger quantities of electricity on the organism. Incidentally the value of artificial respiration after death by electricity was also tested. As this is the minor portion of the work this part will be given first.

The data bearing on the subject in general are quite meagre, especially as to the amount of current which actually passed through in fatal cases.

In all my experiments dogs were used, and in the subjoined table the weight, voltage, amperage and time are given for each case.

In the first experiment 525 volts, 2 amperes were applied for 8 seconds; in the second, 220 volts, 1.2 amperes; in the third, 106 volts .4 ampere, 10 seconds; in the fifth, 96 volts, .35 ampere, 2 seconds; in the sixth, 52 volts, .3 ampere for 1, 2 and 4 seconds; in the seventh, 70 volts, .32 ampere, ½, 1 and 2 seseconds was used.

Before the application of the current a canuala was put into the trachea so arranged that it could at once be connected with a bellows for the purpose of giving very complete artificial respiration. Respiration was set up as soon as the current was off and this was continued for periods varying from 20 minutes in the first case to 2½ hours in the last, and in no instance was resuscitation accomplished.

Further work was carried on for the sole object of studying the effect of the current.

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Our electrodes consisted of oval copper plates 3 by 2 inches, covered with sponges moistened with salt water. One electrode was applied at the base of the skull, and the other over the middle of the back, the hair of the animal having been previously well moistened with the salt solution. The current used was the alternating current of 130 periods per second. While the details of each experiment are given in the table subjoined, a few are selected for special presentation. The larger voltages were abandoned for 100 volts, 70 and 50, as nearly as could be reached.

Ninety-eight volts with .32 ampere were applied first ½ second, then 1 second with recovery, but in two seconds produced death. Fifty-two volts with .3 ampere were applied 1 second, later 2 seconds, with recovery, then 4 seconds, producing death. Fifty-two volts, .24 ampere applied 3 seconds produced death. Fifty-one volts, .12 ampere, 4 seconds; 51 volts, .18 ampere, 4 seconds were not fatal. Fifty-one volts, .2 ampere, 4 seconds produced death. From these figures and similar ones to be obtained from the table, it is evident that the result depends, somewhat independently of the weight of the animal, on three factors: On the voltage, on the amperage and upon the time of application. A variation of either one of these factors may change the result—that is, a lower voltage with lesser amperage applied for a longer time will have the same effect as a current of higher voltage or more amperage applied for a shorter time. In this connection it was suggested by Professor Thomas that the joules necessary would be found the same in each case, and calculations show that this is approximately true. To prove this absolutely it would, of course, be necessary to work with the minimum quantities as to voltage, amperage and time in each case, and no doubt one or another of these factors will be found in excess in most cases. In these experiments it is of great interest to point out this approximate relation between the results, and the absolute amount of mechanical energy used. The results found on post mortem examination of the animals were so uniform that they can be very briefly described. In all cases this examination was made immediately after death, and at first we wished to study the changes produced upon the heart, so that the incision was made through the chest walls and the heart exposed as rapidly as possible. This organ presented the following peculiar conditions. The left side was completely relaxed, the right side was intensely gorged with blood, as were also the large veins in the immediate vi-

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cinity of the heart, and the little appendages of the upper portion of the heart were found beating regularly, strongly and synchronously. Pressure on the heart caused a contraction of the other parts, and from this it was evident the death was not due primarily to the destruction of the heart fibers. In addition it was noted that the deep and extensive cuts made in the tissues were free from blood, and that the arteries were quite small and contracted.

This excluded a direct effect upon the heart, and, having shown by artificial respiration that the stoppage of this function was not the cause of death, other causes were to be looked for.

It was supposed that the current immediately struck the pneumogastric nerve stimulating those fibers which control the heart in that they have the power of arresting its beat, when strongly stimulated. To test this view, resort was had to the hypodermic injection of atropine, the action of which drug is to paralyze the nerve fibers, and thus prevent their action on the heart when stimulated. In one case $1\frac{1}{30}$ grain of atropine was given, 52 volts with .25 ampere was applied first for 2 seconds, then for 4 seconds, and this resulted in death. In a second case $\frac{1}{20}$ grain of atropine was given, 52 volts with .29 ampere was applied first 2 seconds, then 4 seconds, again resulting in death. These animals were not therefore rendered more resistant by the drug, and the theory as to the role of the pneumogastric nerve was abandoned.

I now recall the fact already mentioned, that after death, incisions into the animal are not followed by bleeding, that the arteries are contracted down to a very small caliber, and that the blood is crowded into the very large veins in the trunk. Taking these facts, it was suggested that the current acted upon the arteries through the nervous center which controls their diameter. It is well known that the arteries are supplied with a middle muscular coat in which the fibers are circular, and their contraction would of course cause a narrowing of the artery, rise of the blood pressure, and a consequent impediment of the heart's action; in fact it has been experimentally demonstrated that the arteries can be constricted to such an extent as to produce a rise of blood pressure which the heart is unable to overcome, and that the circulation will stop from this cause. It is further known that we have in the brain, most of the nerve matter whose function it is to control the vaso-motor nerves, the arteries at one time, and in one place contracting and thus decreasing the amount of blood

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at another time and in another place, dilating and thus increasing the amount of blood getting to another particular part. To test this view, that the action of the vascular nervous system was the cause of death, we resorted to the hypodermic use of nitroglycerine. It is known of this drug that it powerfully affects the arterial system, causing, when given in larger doses, an extreme dilatation of the arteries, and a consequent great lowering of the blood pressure.

The first animal received $\frac{1}{25}$ of a grain of nitroglycerine and, when the effects were fully established, a current, which was known to be fatal, was thrown in; namely 50 volts, .24 amperes for 4 seconds, but the effects produced by this current soon passed off and there was complete recovery. Then 97 volts, with .54 ampere were thrown in for 1 second but this caused death. In another case $\frac{2}{25}$ of a grain of nitroglycerine was used; here 52 volts, .22 ampere, a fatal dose, were thrown in for 4 seconds with recovery. One hundred and four volts, .6 ampere were thrown in for 4 seconds producing death, but after the current was taken off there were noted 8 deep but irregular respirations. In other cases where the nitroglycerine was used, there was no apparent effect, but some investigation led me to attribute this to the unreliability of the tablets of nitroglycerine used, and this drug was then abandoned for nitrite of amyl, a substance which has the same physiological effects as nitroglycerine but which can be always obtained pure, and the effects of which can be more accurately regulated because it is given by inhalation. In the first case the animal was brought moderately under the influence of the nitrite of amyl, 52 volts with .24 ampere were thrown in for 3 seconds, (this by the way being a fatal dose ordinarily,) without producing death. Fifty-two volts, .25 of an ampere for 4 seconds, also a fatal dose, failed to produce death. Fifty-two volts, .3 of an ampere for 6 seconds produced death, but after the current was taken off, the animal made 22 deep, regular respirations though not a trace of the heart beat could be made out, this incidently proving that stoppage of the respiration is not the primary cause of death.

Three more experiments may be selected. Numbers 24, 26 and 27 of the table.

No. 24 was a pointer dog in excellent condition, weighing 34 lbs. Nitrite of amyl was given until the effects were fully marked. Fifty and five tenths volts with .2 ampere were given

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for 3 seconds; after a pause the same quantity was given for 6 seconds, followed by recovery. Three days later the same dog, which showed no effects at all of the previous treatment, was given—without the nitrite of amyl—51 volts, .2 ampere, 4 seconds, producing death.

In the last case a dog weighing only 12 lbs. and of such general condition of weakness that the assistant protested against his use as not being competent to demonstrate anything, was given a full dose of nitrite, then 50 volts with .6 ampere were applied for 4 seconds and followed by recovery. The dose applied for 6 seconds produced death and here again several respirations were noted.

The statements made in regard to the cause of death by electricity are so at variance with one another that it is unnecessary to review them here. Among other plausible reasons it has been stated that the current has a direct disintegrating effect on the brain and nerve tissues and that herein is to be found the cause of the fatality. The disintegrating effects of the current on the brain and nerve tissue said to follow, are not to be seen macroscopically and the microscopic examination of these organs so far as made by us failed to reveal any change in their structure. It would appear therefore that death in electric shock is entirely due to the fact that the current produces a contraction of the arteries through an influence on the nervous system, and that this constriction of the arteries throws in such a mechanical impediment to the flow of the blood as the heart is unable to overcome, and that, where drugs are given to counteract this effect, much larger doses of electricity than the ordinary can be borne. While artificial respiration may be of value in simple stunning, when larger doses have been taken, no rational means of resuscitation have as yet been suggested.

I was enabled to carry out the above experiments by the loan of apparatus kindly furnished by Professor Thomas and was greatly assisted in the work by Mr. Boyd, of the Physical Department who was present at every experiment and who made the measurements for us.

The current was obtained from a surface wound alternator giving an approximate sine-curve. For potentials of 100 volts or less, connection was made with the secondary of a suitable transformer. Potentials of over 100 volts were taken direct from the primary circuit, adjustment being made by varying the generator field.

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No.	Weight (lbs.).	Volts.	Amperes.	Time (seconds).	
1	21	525	2	8	Artificial respiration 40 min.—Death.
2	15	220	1.22	8	Artificial respiration 25 min.—Death.
3	30	106	.4	10	Artificial respiration 1 hr. 15 min.—Death.
4	42	98	.4	4	Artificial respiration 2 hrs. 30 min.—Death.
5	27	96	.3	2	Artificial respiration 1 hour.—Death.
6	21½	52	.3	1 2 4	Recovery. Recovery. Death.
7	12	70	.32	.5 1 1. 2	Recovery. Recovery. Recovery. Recovery.
8	40	47.5	.25	4	Death.
9	35	96	.35	1	Death.
10	30	52	.25	2 4	1-30 grain atropine { Recovery. Death.
11	28	52	.29	2 4	3-60 grain atropine { Recovery. Death.
12	26	50 97	.24 .54	4 1	1-25 grain nitroglycerine { Recovery. Death.
13	30	48	.22	4	1-20 grain nitroglycerine.—Death.
14	33	52 104	.22 .6	4 4	4-50 grain nitroglycerine { Recovery. Death.
15	22	51	.32	4	6-50 grain nitroglycerine.—Death.
16	22	47	.2	4	1-10 grain nitroglycerine.—Death.
17	27	52 106	.2 .55	4 1	1-10 grain nitroglycerine { Recovery. Death.
18	36	51	.25	4	80 grains chloral 1-50 grain atropine { Death.
19	30	52	.24	3	Death.
20	51	52	.24 .25 .30	3 4 6	Recovery. Recovery. Death. (22 deep respirations.)
21	25	50.5	.2	3	Death.
22	19	51	.2	3	Small dose nitrite of amyl.—Death.
23	17	51	.2	3	Small dose nitrite.—Death.
24	34	50.5	.2	3 6	Full dose nitrite { Recovery. Recovery.
25	38	50.5 101	.2 .2 .5	4 6 1	Full dose nitrite { Recovery. Recovery. Death.
26	34	51	.12 .18 .2	4 4 4	Recovery. Recovery. Death.
27	12	50	.2	4 6	Full dose nitrite { Recovery. Death

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Voltages were measured by means of a Weston A. C. voltmeter. The mains supplying the current were of low resistance, so that the drop when the circuit was closed was found to be negligible. The figures given are the actual potential differences of the electrodes, while the current was flowing through the animal, correct to within one-half volt. A Siemens dynamometer was used for measuring the current when the time of contact was less than four seconds. It was somewhat difficult to make a setting, so that readings for those short times can not be taken as correct within five per cent.

Discussion.

Mr. G. W. Blodgett:—I would like to ask the author two or three questions. He speaks of applying a current of 52 volts .3 amperes successively to an animal for six seconds. I would like to know what the interval was between those applications?

Dr. Bleile:—The intervals were never timed, but we would wait until the animal had fully recovered, as evidenced by the general condition, which can be readily told. There is always dilatation of the pupils, and you can wait until that goes down, and then the wagging of the tail is a good index of a dog's condition, if he responds freely by a wag to such gentleness as is used with dogs.

Mr. Blodgett:—Would there be an interval of a few seconds?

Dr. Bleile:—Oh it was more than a few seconds. It was from five to ten or fifteen minutes.

Mr. Blodgett:—So that in the second application there could be no effects remaining from any other application?

Dr. Bleile:—No, sir, that is excluded. In fact in this one case, that of the pointer dog, case No. 24, that dog was unloosed immediately after the current was off, it taking just a half minute to unloose him, and he was quite playful and entered into some little sport in that short time after.

Mr. Blodgett:—I have a curiosity to ask one other question, because I am not a medical man. You speak of putting an animal "moderately" under the influence of nitrite of amyl. I would like to ask what the effects of that drug are when used moderately, as in this case, or freely, in other cases. What are the effects which the drug itself would produce?

Dr. Bleile:—The effect would be ascertained by feeling the pulse. The pulse has a certain amount of hardness, and a certain character, which is due to the elasticity of the arterial walls. When the artery dilates, that elasticity is changed, and the charac-

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ter of the pulse wave is changed. It comes up slower, and at the same time there is an increase in the number of heart beats. You will always find that when the blood pressure falls, there is present an increase of the beat, and *vice versa*, there is a compensatory effect. That was, of course, a matter that was merely estimated. We had no means of gauging that; but when we found just a perceptible impression on the character of the pulse and the frequency, I call that "moderate;" and when it was pushed a little, that I call a full dose. It produces in man a great flushing of the face and giddiness.

PROF. JOHN C. SHEDD:—I would like to inquire what means were taken to secure the variation of amperage where the voltage remained the same. I notice in experiment No. 20 the voltage was 52. The amperage in one case was .24 to .25 and .30.

DR. BLEILE:—In those cases the variation was due to the moving of the electrodes. The animal did not remain perfectly quiet, and accordingly as we got greater or less contact the amperage would correspond.

MR. JULES NEHER:—I would like to touch upon the same question. It is natural for electricians to study the relations between amperes and volts. I note that in most of these cases the resistance of the animal is very much the same. In the case of 50 volts and .24 amperes it would be about 200 ohms; except for the last animal Dr. Bleile speaks of, a 12 lb. dog which showed the exceedingly low resistance of 80 ohms, the current being 50 volts and .6 amperes.

DR. BLEILE:— No. 27?

MR. NEHER:—I think it is No. 27; 50 volts and .6 ampere were carried over four seconds, and then six seconds with the deadly effect—I see now that I made a mistake. I understood it was .6 ampere. I see now it is .2 on the table. I have frequently been told by persons who seemed to know something about it, that the current when applied would rise during the application in some way, as if it would find a better path after having been applied for short periods, and I wonder if in these experiments the same phenomenon was proved in longer duration.

DR. BLEILE:—We did not find that, so far as these experiments went. I think that statement has been made in regard to man, and it can be explained in this way. When the current is on, it will in most instances produce a secretion of sweat, and by moistening the skin you get a better conduction, and therefore a rise.

PROF. ELIHU THOMSON:—This valuable paper of Dr. Bleile's reminds one of some matters that were investigated some time ago by the late Dr. Tatum. He carried out his experiments with the idea of discovering the effect of different frequencies in producing physiological effects. As I recall his results, he found that at a certain frequency, which I think was very nearly 60 periods per second, the maximum physiological effect was produced, measuring the current that was passed through the animal. He

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used dogs, I believe, in his experiments, and also the human subject, discovering the limit of endurance or the amount of current which could be passed through the body and sustained without very great discomfort. He found also that as the periodicity rose up to, I think, some 2,500 periods, the immunity from harm by the passage of the current became very much increased; and, if I remember the figures, at about 2,500 periods he passed through the brain of a dog some .34 ampere without any particular effect. I may be mistaken about the figure, however. But it was certainly as large a current, or larger, than that which would seem to be necessarily fatal if of low frequency. It is well understood too, now-a-days, that as we get the frequency still higher, a very considerable current value, if we read the values by the calorific effects, can be sustained by the organism without any apparent injury; so much so that a current which would apparently be large enough to be represented in its calorific effect, by, say an ampere and a half, can be readily sustained by the human subject.

Now, as to the equivalence alluded to in the paper of a variation of the factors of time of application and amperes applied, of course there must be a limit to such a relation. There must be a certain current which can be sustained almost indefinitely, as we well know. We take hold of the terminals of an electric apparatus, and with a certain current we can hold indefinitely, and of course we will have the delivery of energy at a certain rate; piling up, as it were, in the system; so that we must have a lower limit at which the relationship referred to will not hold good. There is another fact which I think may have some influence on the results. That is the question of education of the system to stand the current. I remember some experiments were made several years ago by some of our young men in the Thomson-Houston Company for the purpose of determining what alternating current or voltage they could stand. They began low and gradually worked up, catching hold, of course, of the wires, using the hands. They found that beginning at, say 50 volts, and increasing the voltage, they could take shocks of 450 volts alternating current, at which point they had to desist. It made them sick for the afternoon, but no other harmful results followed. Of course a very severe shock was received. Whether the system could have stood such an application at once is questionable. I think very likely the shock might have been fatal; but by gradually, as it were, bringing on the power of resistance, somewhat in the same manner that power of resistance to the action of drugs may be brought on by the administration of small doses at first, then larger and larger doses, the system seems to have the power of setting itself against adverse influences providing it is given time.

An interesting question arises in connection with the results given in the paper in regard to high frequency. I have in mind having seen the statement published some time since in regard

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to the effects of high frequency currents passed through the animal system, that a very great relaxation of the arterial and capillary systems takes place; that such is in fact the effect of the passage of high frequency currents; that a wound made after the passage of high frequency currents bleeds very freely. If that be the case, then we have the interesting speculation as to whether instead of administering nitroglycerine or nitrite of amyl we should not administer high frequency currents and relax the whole arterial system, and thereby cause instant recovery. I merely throw this out as a suggestion, a field for work that might produce valuable fruit, or might not.

MR. NEHER:—The discussion thus far has been on the effects of alternating currents on the animal body. I wonder if anybody can inform us of the effects of direct currents. It has often been suggested that direct currents would have a more severe influence on animal life, owing to the powerful electrolytic effect produced either in the nerves or in the system of the blood vessels. It is understood, I think, that with a high potential direct current, shocks were usually sustained by getting in contact with an arc circuit. There I suppose that the potentials rise to enormous values the moment the circuit is broken, and that death is probably due to the very high potential. There may be some person that can tell us what happens with comparatively low direct current voltages as they are in use on railway circuits.

MR. GARRATT:—I notice a little error here that should be corrected. On page 392, in the middle of the third paragraph, it says: "In one case $1\frac{1}{30}$ grain of atropine was given" Evidently that should be $\frac{1}{30}$ grain instead of $1\frac{1}{30}$, as that would have been fatal anyway without any electric current.

In regard to death from direct current, none of us can give the answer desired, because none of us has been killed yet, but I saw a man come very near it once with a current impressed by about 750 volts. It could not have been much more than that, and how much less I cannot state, because I do not know what the resistance of his body was. The conditions were these: A large storage battery had been placed in series for the purpose of testing, and I had the terminals of the system in my hand, both hands wet with the weak sulphuric acid solution, giving very good contact; and one of those inquisitive individuals who are constantly opening and shutting switches to see what will happen, pulled down the main switch which was located in an adjoining room of humble name but undoubted utility, and left me in the circuit. I was knocked insensible. Some one who happened to be near by pulled me off the circuit, and I came to. I will not take the time of the INSTITUTE in describing my feelings. In fact I do not think I am adequate to it this morning. But it was a case of severe shock producing insensibility by a pressure of something like 750 volts; my hands were not badly burned. Two or three times in my experience I have got afoul of arc light currents.

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I remember not long ago doing one of those foolish things which some of us will do sometimes. I was standing at a T.-H. arc machine adjusting the brushes on the right side and happened to notice the oil cup dripping into the air-blast was not feeding, and instantly I reached over to adjust the oil cup with one hand and held onto the brush with the other, and was brought directly across the circuit. It was a shunt across the 20-light machine, with, I think, 18 lights burning at the time. It did not produce insensibility. So the storage battery current at a comparatively low voltage does produce a more serious effect, or it did in my case, than the kick that follows from an arc light machine, though, of course, the contact was not so good in the latter case. There is a question I should like to ask Dr. Bleile. Is a fatal shock produced by a momentary contact either with a direct or an alternating current, from the effect upon the pneumogastric nerve, preventing heart action from going on, although none of the nervous or muscular mechanism is destroyed? Is death produced by a shock which does not destroy any of the nerve or muscular fibre?

Dr. Bleile:—We have what is known as surgical shock. That is a term familiar to all of you. The pneumogastric nerve is a little peculiar in its action, as I have already mentioned, and it is particularly susceptible to so-called reflex stimulation, or excitation. For example, some of us, I dare say, have run through buildings in course of construction and fallen through and struck a joist, and had "that tired feeling" known as fainting. That fainting feeling is due to momentary suspension of heart action through a reflex effect coming by means of the pneumogastric nerve, the bundle of nerves through there being in pretty direct communication. Then we have another set of nerves connected with the teeth, branches of the fifth pair, and that accounts for the deaths that often occur in the dental chair. A tooth is extracted and that produces a powerful impression on this nerve, which passes back to the medulla, is reflected over on the pneumogastric nerve, and stops the heart. The same thing occurs sometimes when people fall dead on the receipt of sudden news producing a violent emotion, either pleasant news or news that is unpleasant. Fainting is not uncommon under such circumstances, and deaths have been reported. Now, all that comes from this reflex effect on the pneumogastric; and I think in man another effect comes in, namely, the physical factor, something which exists only to a very slight extent with the lower animals. Then I think some people are scared to death in just this way, through fright.

Prof. Anthony:—I should like to ask a question. I confess to no knowledge on the subject myself. In regard to the effect of the high frequency current, is it certain that the current does pass through the body? When we have a high frequency, does the current that we have in the conductors outside, go through the

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body, or does the body act as a sort of condenser. If the current gets into the surface, or into the electrodes perhaps, and really does not go through, then we really do not get as much energy in the body as is represented by the current that passes through the wire. Under certain conditions—and it does not take a very large condenser either—we could have a condenser effect such that there was no current whatever passing through the circuit, the energy simply going into one side and out again. May not the human body act in something the same way with these very high frequencies.

PROF. THOMSON:—I think I can answer the question. I particularly arranged an apparatus to discover whether the action of the body as a condenser had much to do with the phenomena. To dispose of the action of the body as a condenser we may imagine this condition of things: a person on the other side connected with the other terminal, and an incandescent lamp between. If their capacities are nearly the same, as they would be, then that incandescent lamp should not light if the current does not pass through the body. But the incandescent lamp does light, and lights just the same, and with the same intensity as if it were interposed between one person and a terminal and the hands were joined, having the same brilliancy under the same conditions. That indicates, of course, that the current which carries energy does pass through the body. Another way in which the same indication may be arrived at. If the body be supposed to act as a condenser, how about the arm that receives the discharge? The arm is not the condenser. It must act as the conductor to a condenser, and it is possible to take sparks that will melt wire, that will light incandescent lamps to a very high brilliancy, through the arm without producing any sensation in the arm. Furthermore, if the current travels through the body by being confined to the surface, then if the nerve sensibility is more active at the surface, we certainly should have more effect at the surface, unless there is some peculiar direction of flow which prevents the carriage of the impression to the nervous organism. But if you take hold of a handle of limited surface; if, for example, a metal tube be held in the hand as an electrode, and crowd the current to a point at which you will feel a decided stinging sensation, you do not feel that current around the edges of the contact, but you feel it all over the section, the current is entering throughout the section of the skin exposed to the metal. This indicates that the current does penetrate into the tissues, and passes right through the nerves of sensation also; but it requires a very considerable density to excite them. One can carry quite enough current to light an incandescent lamp through the little finger, as I have tried. I have put a ring around the little finger and lighted an incandescent lamp by current passing through the finger. The contact surface was very sensitive, but the current passed did not harm the finger. One could feel the sensation of

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warmth throughout the finger, and not alone on the surface of the finger either; apparently deep seated. I could not say whether the impression was exact or not, but so far as one can judge it is deep seated, especially at the knuckles, where there are large bones producing resistance. Furthermore, if you dip your hands into brine up to about the wrist and take a heavy, high frequency current through the body, the concentration of heat at the wrist is very noticeable. One feels a warmth not at the surface, or as though the current passed on the outside skin, but right in at the bones, interiorly, apparently, where the current crosses the joint tissues. I think there are plenty of instances that I might cite which indicate that we do not have here simply condenser action, but a real conduction of current. Another thing. I constructed boxes filled with damp sawdust to take the place of the body, so as to have them on hand, supposing that I might need them. It was not always convenient to have human subjects around. I arranged the apparatus (boxes of sawdust slightly dampened with weak brine) with metal plates for electrodes that could be introduced deeply into the sawdust anywhere at all. I found on making the test that I could get indications of current flowing anywhere between the plates by introducing insulated electrodes deeply into the sawdust. Furthermore, I replaced the sawdust boxes without otherwise changing the conditions, making the conditions absolutely identical in all other respects, by water rheostats, and measured the elevation of temperature in those rheostats during a certain interval of time, and I found that with the water rheostats replacing the sawdust box, under equal conditions (and that is about the only way we can deal with these currents), a horse-power of energy was delivered to the water rheostat; that is, the energy was delivered at the rate of a horse-power, and that energy must have been delivered to the body under similar conditions at the rate of a horse power. Now, I hardly think that such an amount of energy could have been given to it by a condenser action. It must have been by some other action, resistance of the body opposing the current, So I think, when we look closely into this matter, and take all these considerations together, we have ample proof that there is an actual passage of a considerable current through the tissues of the body; perhaps not evenly distributed, perhaps following the channels nearer the surface, perhaps following the blood streams, depending, of course, upon the local conditions.

Mr. Blodgett:—Prof. Anthony asked, and Prof. Thomson has answered the very question that came into my mind, whether the current was confined to the surface or whether it actually passed through the tissues of the body. In Prof. Thomson's experiment where he immersed his hand in salt water, and observed the sensation at the wrist, it would seem to me that if the current was strong enough to produce a sensation there, it should have produced it through the whole section of the arm, or, at least, at the

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joints, where there might have been a greater resistance, or for some other reason the sensibility might be greater. I would like to ask whether he did discover any sensation above the point where it was immersed in the salt water.

PROF. THOMSON:—The particular sensation that attracted my attention at the time, was at the wrist in that experiment, and I explain it by the fact that the section farther up is continually increasing, while at the wrist there is probably a minimum of tissue. The bony mass there is the major part of the section, whereas above the elbow there is a much greater mass of muscular and other tissues which would be full of conducting fluid also. I did, however, on still further pressing the experiments by immersing the wrist,—seeing that the wrist was the resistance in circuit,—try to get rid of resistance in circuit and reduce it still more by putting a portion of the forearm into the brine. Then the sensation of heat at the wrist stopped, and the sensation of heat was transferred to the forearm just above the brine. There is undoubtedly a peculiarity noticeable in these cases, that the heat sensation is just above the line of entrance of the current; at least it appears so; although in the case of passing current through the little finger, the heat sensation appeared to be throughout the finger and at the joints. It is difficult, of course, to locate so indefinite a sensation. It naturally is graded off in both directions, and all you can say is, "it is about here."

MR. WALTER E. HARRINGTON:—I would like to ask Dr. Bleile if he can explain a certain action that the electric current has on crabs. I made some tests on crabs a few years ago with a 500-volt direct current; took a lamp circuit, five 16 C. P. lamps in series, and placed one terminal of the circuit on the crab's back, and then touched each one of its fingers or legs, —I do not know what you would call them—and as I touched them they would throw them off; throw them away several inches. I did that with half-a-dozen different crabs, and never have been able to find out the cause, or the reason, the crab would do that.

DR. BLEILE:—Did I understand you to say it cast off the legs?

MR. HARRINGTON:—Yes, throw them several inches.

DR. BLEILE:—Five hundred volts?

MR. HARRINGTON:—Yes.

DR. BLEILE:—A very violent contraction will have that power, or at least there is the ability to throw off members by a violent contraction of the membranes, and you get excessive muscular contraction there, enough to throw them off.

PROF. THOMSON:—I might remark in this connection that I have understood that whenever another crab gets hold of a leg firmly and won't let go, the first one throws off the leg, and the particular crab in question may have thought that the 500-volt current he got was another crab.

MR. BLODGETT:—I recall certain lectures on zoology to which

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I listened a good many years ago, on a certain form of land spider that has that same faculty, namely the ability to throw off its legs; if you pick one up in your hand, it is liable suddenly to drop off one leg after another until it wriggles out of your hand with a spherical body and no attachments whatever, and presently it grows a new set of legs at his convenience.

MR. HARRY ALEXANDER:—On one occasion I was testing a motor, 500 volts, and remember distinctly that the voltmeter read 570 volts. We had a Weston ammeter there, with both binding posts on one side, and we had a single pole switch for short-circuiting the ammeter. At the time I thought I had short-circuited the ammeter, and although the motor was being tested, I at once unscrewed the leads to place them on an instrument of smaller degrees. I took the lead leading to the binding post, unscrewed the binding post and pulled it apart. I received a terrific shock, and should say held on to it for quite some time, but convulsively I let go of it, and as I let go of it, my finger that had hold of the thumb screw of the ammeter blistered up quite perceptibly. The way I was affected by the shock was that for almost an entire week I was taken with severe vomiting spells as well as convulsions, generally in the evening before retiring. I called in the doctor, but he did not attribute it to the shock. He said, if I had ever got the shock of that voltage by unscrewing the ammeter, I would have been dead long ago. He said I was suffering from a cold and had disarranged my stomach. So I should like to have the Doctor explain the effect it had upon me, if possible.

PROF. CROCKER:—I know that I speak the sentiments of the INSTITUTE in acknowledging our great indebtedness to Dr. Bleile for this interesting and able paper. It would have been to his own interest to present it to some medical journal, but our interest in this subject is so great, that we appreciate it highly. I therefore move a vote of thanks to Dr. Bleile for his important paper.

[The President put the question on the adoption of the motion, and it was determined in the affirmative.]

The Secretary announced that the Cataract Construction Company had donated to the members of the INSTITUTE in attendance at the meeting, copies of the Niagara edition of *Cassier's Magazine*, which would be distributed later.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th 1895, President Duncan in the Chair.

LONG DISTANCE TRANSMISSION AT 10,000 VOLTS.

(The Pomona Plant.)

BY GEORGE HERBERT WINSLOW.

The Pomona plant was installed in the summer and fall of 1892 for the San Antonio Light and Power Company, of Pomona, Cal. It was increased in the following spring, and early last year the capacity of the plant was doubled by duplicating the entire equipment. At the present time, when the plant has been in regular operation for more than two years, and its complete success has established confidence in the successful outcome of many similar projects of greater magnitude, it seems fitting to present a careful description of the entire installation. The electric plant was installed under the personal direction of the writer, as electrical engineer, who presents many of his personal observations on its construction and operation.

The plant is used to transmit energy from a waterfall to substations at Pomona, 13¾ miles distant, and San Bernardino, 28¾ miles distant, from which points it is distributed for incandescent and arc lighting. It consists of a Pelton water power plant and a Westinghouse alternating current transmission plant in which generators supply currents to sets of raising and lowering transformers operating at 10,000 volts, and delivering current to the local circuits at 1,000 volts.

The water power for this plant is derived from the San Antonio creek, which is chiefly supplied by the melting snows and the rains on San Antonio Mountain. Side canyons, however, also furnish some water. The creek flows for several miles through a narrow valley at the upper end of the San Antonio canyon in a bed which it has washed for itself in the layer of

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boulders and gravel formed by the action of an immensely larger stream in past ages.

At the lower end of the valley, a sharp ridge extends eastward from the side of a neighboring mountain, from which it originally split off, and blocks up the valley except at a narrow place at which bed-rock is exposed, and through which the stream plunges suddenly downward at least 90 feet between precipitous walls of rock, forming the San Antonio Falls.

To utilize this fall, part of the water is diverted by a dam about 200 feet above the falls into a canal which conducts the water to a tunnel passing through the ridge. At the other end of this tunnel, the water enters a large pipe leading to the power-house, which is located 412 feet below the level of the outlet of the tunnel.

Pipe-Line.

A vertical projection of the pipe-line, giving the sizes of the pipe, is shown in Fig. 1.

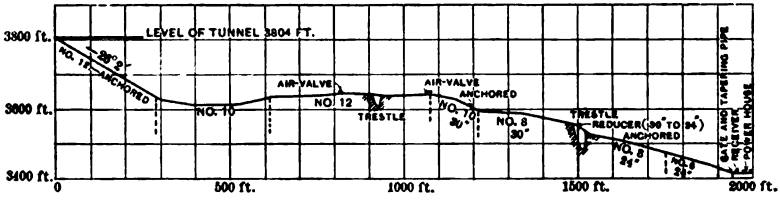

Fig. 1.—Pipe Line, Pomona Plant. Effective Head 390 feet.

The pipe is of sheet steel, double-riveted throughout, and was delivered on the ground in sections having a length of 11 feet 6 inches. These sections consist of four sheets, each three feet long.

The diameter of the pipe up to within 450 feet of the power-house is 30″, with the exception of the length which connects it to the sand-box at the top of the pipe, which length is considerably expanded, so as to allow the water to flow slower on entering, and thus to reduce the entrainment of air. Near the power-house a "reducer" is inserted in the pipe to reduce the diameter to 24″, and this size is maintained from this point to the power-house. The pipe was designed to carry 2000 miner's inches of water (measured under a head of 6 inches), without unnecessary loss by friction. The capacity is equivalent to 50 cubic feet per second, or 1882 H.P. at 390 feet effective head, assuming

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a wheel-efficiency of 85 per cent. This is nearly three times the power for which the present station was built, but the extra capacity of 1000 horse-power obtained by increasing the capacity of the pipe costs so little when compared with the cost of building an entire new pipe-line, that it is much more profitable to lay the larger pipe in the first place, if sufficient water can ultimately be developed to utilize the added capacity.

The thickness of the pipe is increased as it nears the power-house, to provide for the increase in pressure in the lower parts. At the first bend it is made greater than that of the sections above it on either side, because the pressure on it there is greater. After passing the second air-valve, first No. 10 and then No. 8 steel is used, the latter size being continued to within a short distance of the power-house. The last few lengths are of No. 6 steel.

The horizontal distance between the mouth of the tunnel and the power-house is 1940 feet, and the difference in level between the tunnel and the floor of the power-house is 412 feet. The total length of the pipe is 2370 feet.

The sections of pipe as received from the makers were coated with asphalt both inside and out, and parts of this coat were of course scraped off through rough handling. After the pipe was laid and jointed, a man went through it and painted the joints with hot asphalt to prevent rusting.

In order to protect the pipe from the great changes in temperature which occur in the mountains between midday and midnight, earth and loose rock were placed around and on top of the pipe without any tamping, and where enough earth could not be conveniently obtained, brush was cut and piled on the pipe and covered with a light layer of earth and rock.

The lower end of the pipe is closed by means of a 24 in. Ludlow gate-valve, which is bolted to a cast-iron flange riveted to the end of the pipe.

The stem of the valve is geared to a small hand-wheel, partly on account of its weight, but chiefly in order that the gate may not be shut too quickly, as otherwise the pipe would be subjected to severe strains, resulting from suddenly checking the velocity of the column of water. For use under heavy pressures the gearing is also necessary in order to be able to move the valve at all. The head of water on this plant is so great that it is impossible to open the valve while the pipe is full, and the receiver empty. It is therefore necessary to equalize the pressure by filling the receiver through a by-pass, or to partially empty the

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pipe by means of a relief-valve attached to the pipe close to the gate. The relief-valve is primarily designed to protect the pipe from shock by allowing the escape of a considerable quantity of water in case of an increase of pressure in the pipe; such, for example, as would occur should any obstruction partially close the opening of the gate. It has a circular valve so proportioned that a slight movement of it will afford a large opening for discharge. The valve is held in place by a weighted lever, and is set so that a very slight increase above normal pressure will cause it to open.

The gate is connected by a tapering pipe of steel to a horizontal, cylindrical steel receiver 20 feet long and 42″ inside diameter, from which the water is distributed to the wheels. The object of such a large receiver is to avoid the loss in head which would be occasioned by the eddies formed when drawing the water from the side of a smaller pipe. It also serves to keep air from being drawn into the discharge pipes in case it accumulates in the receiver. (Last year the receiver was lengthened to 48 feet.) An air-valve is placed at the top of the receiver. Two tapering cast-iron pipes (a large and small one) are bolted to the lower side of the receiver at an angle of 30 degrees.

Water-Wheels.

The above pipes conduct the water from the receiver to the under sides of two independent Pelton water-wheels, which drive an alternating current generator and its exciter.

To the end of each pipe is attached a Ludlow gate-valve, the stem of which passes horizontally into the dynamo room through a bushing in the concrete wall. The larger of the two stems is geared to a hand-wheel; the other is fastened directly to a smaller hand-wheel. The flow from each pipe can thus be completely controlled from the dynamo room. The pipe running to the generator wheel is provided below its valve with two nozzles cast in one piece, and attached to the valve by means of a limited ball-and-socket joint, which permits them to be moved vertically to deflect the water. (See Fig. 2.)

The pipe supplying the exciter wheel has below its gate a throttle-valve, the stem of which passes through the wall into the dynamo room, where it can be connected to a governor. The wheels are located directly below the receiver, and above a raceway which conducts away the water after it drops from the wheels.

The speed of a Pelton wheel is dependent for a given load and head of water upon the amount of water striking the wheel,

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and therefore to maintain a constant speed this amount must be changed every time the load changes, and in proportion to the latter. In the case of the generator-wheel this change is produced by deflecting the water. Constant-speed regulation may also be obtained by throttling the water, as is done in the case of the exciter-wheel. When the water is throttled there is loss in efficiency due partly to the scattering of the water as it flows from an aperture which it no longer completely fills (which causes much water to miss the buckets), and partly to the loss of head caused by friction in passing through the valve. With the deflecting nozzle there is no loss of efficiency due to this cause. There

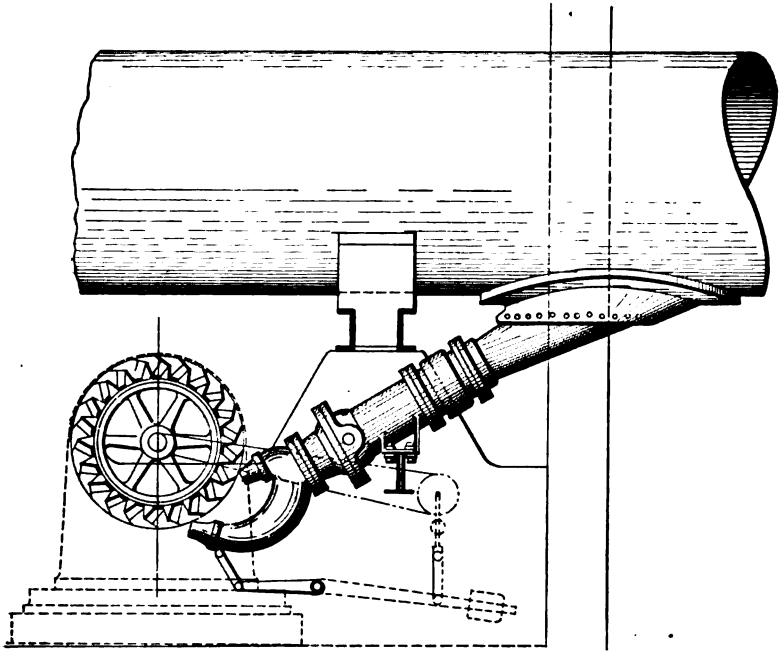

FIG. 2.—Pelton Water-wheel with Deflecting Nozzle.

is, however, a great waste of water at light loads, since under a constant head the same quantity of water must be disposed of at all loads, and for light loads the greater part of it is wasted. To avoid this loss the use of a reservoir naturally suggests itself. It is an unfortunate fact, however, that high heads are confined to mountainous countries and that there a reservoir usually necessitates a high and consequently costly dam. The necessity of building a dam to withstand freshets so increases its cost as to make

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the use of a reservoir commercially impossible with high heads. Therefore, the water must continue to be wasted, and the chief apparent objection to deflecting nozzles is seen to be of no importance.

A set of tips of different diameters is supplied with each nozzle, so that the size of the jet used may correspond to the maximum load, and thus unnecessary waste of water be avoided. The tips for the generator-wheel range from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter, while those for the exciter are from $\frac{7}{16}$ to $\frac{3}{4}$ inch. When tips are used of the proper size for the full load there is no need of throttling at the full load, and, therefore, no loss from this cause; and with the deflecting nozzle there is no waste of water at full load, so that for full load the two arrangements are equally good. This is not, however, the normal condition of operation of a lighting plant, for in such a plant each dynamo is driven by a separate wheel, and the load is constantly changing, so that here the deflecting nozzle has the advantage. The deflecting nozzle is also to be preferred under high heads, to avoid the risk of straining the pipe by suddenly checking the flow of water, as would be necessary with a throttle valve if the entire load were suddenly thrown off.

Regulation by throttling is, therefore, only advisable in cases where the head is not excessive, and where the quantity of water obtainable is limited, as is the case where it has to be stored in, and supplied from reservoirs, or when the supply is liable to sudden stoppage. The writer recalls instances of its value in cases which occurred while he was at Bodie, Cal., in the fall of 1893. There the water was conducted 4,700 feet in an open ditch to the pipe, and was delivered by the pipe under 350 feet head to drive an electric generator for a 12-mile synchronous power transmission. In cold weather anchor-ice would form and suddenly block up the ditch at some curve, and the water-pressure would begin to fall slowly, owing to the gradual emptying of the pipe, which could no longer be kept full by the diminished flow from the lower end of the ditch, which now acted as a reservoir. Having throttle valves in the nozzles, however, very little water was wasted, and the plant was thus kept running until the ditch was cleared, whereas with a deflecting nozzle the pipe would have been quickly emptied, even if the gate-valves had been used as throttling valves (which is feasible if the load only varies slightly). Sometimes the head became so low that it

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was necessary to throw off part of the load and to run at reduced speed, to keep the motor in synchronism.

Governor.

As already stated, the speed of the generator-wheel is maintained constant for different loads by deflecting the stream. This is done by raising or lowering the deflecting nozzles from the the dynamo-room by means of a lever fixed to a shaft which passes through the wall. The position of the nozzles is controlled automatically by means of the Pelton differential governor. The ability of this governor to keep the generator at a practically constant speed depends on the governor being driven at a constant

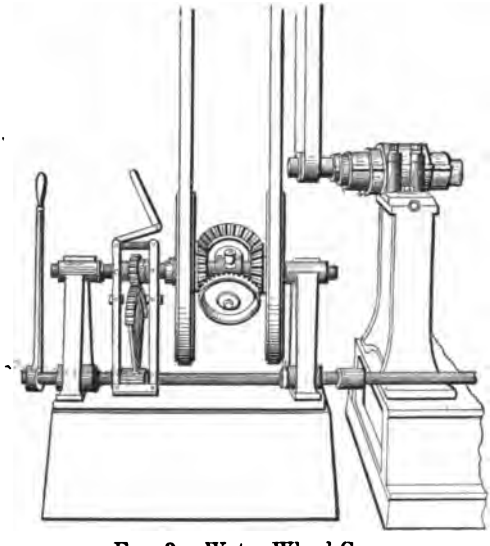

Fig. 3.—Water-Wheel Governor.

speed. I say *practically* constant, for there must be *some* change in speed before the governor can act, and then an appreciable time is required for this action to produce its effect. The constant driving-speed in the present case is furnished by the exciter-wheel shaft. The arrangement for governing is briefly as follows: The generator is geared to stop itself by turning the water off the wheel, and the source of constant speed is geared to speed up the generator by a contrary action. These two actions neutralize each other when the generator-speed is the same as the fixed speed, but when either preponderates the difference acts. Thus an increase in generator speed will act to stop the generator, while a decrease, by making the fixed speed predominant, acts

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to speed up the generator. The governor consists, in part, of two similar miter-wheels which are mounted upon pulleys and placed face to face, loosely, upon a horizontal shaft, and are driven at equal speeds in opposite directions, one by the generator shaft, and the other by the exciter shaft. The speed of the pulleys is 200 R. P. M. In Fig. 3 it will be seen that between these wheels, and at right angles to the supporting shaft, there is fixed to the latter a cross-bar carrying two miter-wheels, one at each end, which mesh with the two oppositely-revolving miter-wheels first mentioned. The result is that as long as the two outside wheels are revolving at the same speed, the two central wheels will merely revolve upon their axes without tending to move in either direction the bar upon which they rotate. Now, if the generator-speed increases, the corresponding side of each central wheel will have to travel faster forward than the other side travels backward, and the difference between these two movements will result in a movement of the central wheels in the direction of the faster wheel, and the cross-bar will consequently move the same way. The shaft to which the cross-bar is attached will, of course, turn with it, and as this shaft carries a pinion meshing in a toothed quadrant connected to the lever which controls the nozzles, the stream will be pulled away from the wheel until the generator speed falls to its normal value. This point is quickly reached with a full load, owing to the drag of the load, but for a light load the inertia of the armature and wheel prevents them from responding so readily, and the governor does not act quite so quickly. Consequently the generator is not only brought to its proper speed but is carried slightly above it, which causes the governor to reverse, and thus sets up a slight and regular *see-sawing* in the speed. This see-sawing will be increased if there is any lost motion in the governor and its connections. It will also be increased because for a full head and light load the jets only impinge slightly on the buckets, and since the jets are round, and their upper edges alone strike the buckets (which are themselves curved in the opposite direction) a slight movement of the governor produces a much greater change in the speed of the wheel under light loads than when the whole of each jet is in use. This effect of the jets is more marked when the governor is working to cut down the speed than when it is increasing the speed, because *withdrawing* the jets a given distance causes a greater change in the quantity of water striking the buckets than would be caused

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by *advancing* them an equal distance. The see-sawing will be further increased if the nozzles are not fully counter-balanced, as they would then tend to fall away from the wheel.

In order to avoid see-sawing it is the practice in this plant to reduce the head every morning during the light load. This was at first done by opening the extra 4″ relief-valve and allowing water to escape until the pressure had gone down to that corresponding to the desired head. The valve was then set tentatively until the pressure became nearly constant, when the final adjustment was made by partly closing the valve on the generator-wheel pipe. It was afterward found that the working pressure of the water at the nozzle could be sufficiently reduced by the last mentioned valve without also reducing the quantity of water in the pipe, and therefore the relief valves are no longer used for this purpose. In either case the governor throws more and more of the stream onto the wheel to compensate for the decrease in head, and the see-sawing stops. Where a double deflecting nozzle is used, it would seem advisable to have in the upper branch a throttle valve so connected to the deflecting levers that when running under light load the valve would be entirely closed and the regulation be attained by deflecting the open nozzle. When the whole stream of this nozzle had came into use and more water was required, the valve would be opened. In this way the water would be used during light load under more favorable conditions than obtain with a simple deflecting nozzle, see-sawing would be avoided, and in case the supply of water became less, either suddenly, as by a sharp freeze, or gradually, because of diminished rainfall, the water would be used most economically and efficiently during the time of maximum load, which is the critical time. The effect of such an arrangement of the nozzles and valves would be to increase the capacity of the plant for a given minimum water supply, the period of minimum supply being precisely that in which all possible economies are of value. It may be objected that tips of such a size should be used as would bring both streams into full use during maximum load, and that then no valves would be required, but against this is the fact that the maximum load (particularly in a lighting plant) does not reach the same value every night and that it is, therefore, always necessary to use tips large enough to meet the possible demand of any night.

In order to avoid breaking the teeth of the quadrant in case the governor should continue to act after it has moved the nozzles

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to either their highest or their lowest point, the pinion on the governor shaft is mounted loosely between two laterally movable toothed ratchets which normally hold it in a fixed position. When the quadrant reaches either of its extreme positions, one of these ratchets will be disengaged by an adjustable lug on the corresponding side and end of the quadrant, and will thus allow the pinion to stop, though the shaft continues to turn. Both ratchets may be instantly disengaged by hand, and the position of the nozzles be regulated by a hand-lever when starting up, or in case of accident to belts or of decrease in head of water.

To start the plant, the governor ratchets are first disengaged, and the exciter is brought to a moderate speed; the generator is then started and its field is charged; it is then brought to about three-fourths of its full speed, and the speed of the exciter is then slowly increased until the cross-bar on the governor ceases to move. At this moment the ratchets are thrown in, and the governor takes charge of the generator-speed. The speed of the exciter is now slowly increased to its full value, which of course brings the generator to full speed.

The speed of the exciter-wheel is regulated by a small throttle-valve, the changes in the position of which do not have any noticeable effect on the pressure in the pipe, owing to the small size of the jet controlled. This valve is so made as to have an equal pressure on each side of its axis when partly open, and hence can be moved from one position to another with little effort, which makes it of special value for use with automatic governors. When tightly closed, however, the areas subjected to pressure are no longer equal, and the valve sticks tightly.

An effort was made to automatically govern the exciter by means of a ball governor driven by a belt from the exciter-wheel shaft, and actuating the valve by means of two leather friction-cones acting alternately on a beveled disk geared to the valve, but this proved unsatisfactory and was finally discarded, chiefly on account of the difficulty of maintaining the proper adjustment, by reason of the wearing away of the cones and of their swelling from dampness. The exciter was therefore controlled directly by hand for a long time. At present the valve is worked from a distance by a simple electrical arrangement devised by Mr. Imlay, in which advantage is taken of the fact that when the exciter is at full speed the movements of the valve necessary to regulate the speed are small.

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The device consists essentially of two fixed solenoids in series, energized by current from the exciter, and normally acting with equal force on two iron cores supported respectively at the opposite ends of a walking-beam connected by levers to the valve, their normal function being to keep the valve stationary. Either of the coils may be short-circuited at will, by means of a relay controlled by two keys and likewise actuated by current from the exciter. When either coil is short-circuited, it ceases to hold its core, and the core on the other end of the walking-beam is pulled down by its own coil, thereby turning the valve in a corresponding direction. In order that this movement may not be too rapid the coils and cores are immersed in oil, which causes the coils to act as dash-pots to the cores; by this means the movement of the valve may be made as slight as is desired.

The relay is not really necessary, but was used to break the circuit in experiments made before the plan of short-circuiting one coil was devised, and has been retained because very convenient. A momentary closing of either key suffices to correct any change of speed, such changes being indicated by the compensating voltmeter. The current in the coils is reduced by a resistance in series with them about equal to that of one coil, and the current for the relay is shunted from the resistance at about two volts. The current normally passing through the coils and resistance, is about two amperes at 100 volts (about $\frac{1}{4}$ H. P.) and when one coil is short-circuited, the current in the other increases to three amperes, so that the maximum power used is $\frac{3}{8}$ H. P.

Power-House.

The power-house is 66 ft. long by 30 ft. wide, and has walls $12\frac{1}{2}$ ft. high. The walls, which are of concrete, were all built by tamping concrete in a space between temporary wooden walls forming a mould, a few feet of wall being built at a time and the planks then loosened and raised to the height of the next section, the walls being thus made at the least expense for timber. The best English Portland cement was used. The walls were consolidated and cement saved, by the use of well-washed fragments of rock imbedded in the concrete. In order to obtain the greatest available fall, the power-house was placed as far as possible below the level of the fall. This necessitated blasting into the side of the hill so far that the entire wall next the hill was below the level of the adjoining rock.

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The station was built to accommodate four 120 K.W. 7,200 alternation, 12-pole, single-phase Westinghouse alternators, with their full complements of raising-transformers and switchboard apparatus, and two exciters. The first installation consisted of one generator with one 90-ampere 125-volt "I" exciter, capable of exciting the four alternators, and of 240 K.W. capacity of oil transformers in 40 units of 6 K.W., 21 of these being located at the power-house.

Transformers.

Several different methods of connecting the raising and lowering transformers were given careful consideration, the test of actual use favoring a series connection for both primary and secondary coils of both sets of transformers, a plan which had proved to be thoroughly reliable in its practical operation at the Westinghouse plant at Portland, Oregon. It was however decided, in order to be able to change the initial pressure on the line in case of accident to any of the transformers, to connect the primary coils of the raising transformers in multiple to the dynamo, put the line coils all in series with the line, and with a similar set of coils in the lowering transformers, and connect the other coils of the latter in multiple to the distributing circuits.

The next question was what size of transformers should be used. Many small transformers meant less cost per unit for repairs, greater facility of handling, and greater flexibility in case it were desired to change the voltage on the line. Their use, however, also meant greater first cost, more complication, and somewhat lower efficiency, but these points were outweighed by the former, and a transformer unit of 6 K. W. was chosen. Each transformer is contained in a cast-iron box provided with vertical outside ribs, which serve to stiffen it, and also to cool the oil with which the box is filled, and which entirely covers the transformer. The box is covered by a cast-iron lid, which has conducting and radiating ribs both outside and in, the inner ones dipping into the oil at its hottest part and helping to cool it. The oil when heated rises through open spaces around the coils and spreads out in all directions, guided by the ribs on the lids, and sinks slowly down between the core and the sides of the box, thus having ample opportunity to become cooled. Each box is provided with a pet-cock at the bottom, by which to draw off the bottom layer of oil, should it become too thick by evaporation. It

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also has an oil-gauge to show whether the tops of the coils are completely covered without having to raise the lid. The boxes are supported upon a substantial timber frame, upon the top of which two iron bands serve incidentally to protect the wood, but chiefly to metallically connect the boxes to each other and to the earth, in order to dissipate the static charge received by the boxes, which is very unpleasant. The core of the transformer is connected to the box by a copper strip fastened around a block of wood upon which the core rests in the box. To provide against the danger which would result from accidental connection between the primary and secondary coils, an insulated sheet of copper is placed between the latter and close to the dynamo-coil, and is connected to the core by a tongue which is stuck between the plates.

The line-coil, of No. 7 B. & S. gauge wire, is inside the dynamo-coil, and is kept everywhere at a distance of one-half inch from the latter, the ground plate, and the core, by walnut blocks boiled in paraffin, between which ample openings are left for circulation of the oil. The ratio of transformation is 1000 to 450, so that in a bank of twenty transformers the dynamo-pressure required for 10,000 volts on open circuit is 1110 volts, and on full load about 3 per cent. more than this, or 1140 volts. The space between the 1000-volt coil and the core is one-eighth of an inch. The terminals of the line-coils are brought up through the oil in mica-fibre tubes passing through heavy glass bushings held in paraffined wooden blocks which are attached to the sides of the boxes. The 1,000-volt terminals are similarly supported, but without glass bushings. The transformers are all connected in multiple to the dynamo-circuit, which is supported directly above them on a light pine framework which also supports the fuse-blocks. The latter are single-pole, and the fuse passes through a hole in a marble block, the object of so confining the arc being to blow it out by its own force. Only one fuse is used on each transformer. The secondary or line coils are all connected in series by U-shaped insulated wire connections which may be readily detached when making periodical tests for insulation of terminals, and which are entirely independent of the frame-work supporting the dynamo circuit. Accidental contact with the exposed connectors is prevented by the framework above mentioned, and there is an inflexible rule that the high tension side of the transformers shall not be touched under any circumstances whatever while the dynamo is running.

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Clark's insulation is used on all wires connected to the transformers and to the dynamo, and the terminal wires of the full bank, which must often be disconnected for testing, are further insulated by heavy glass tubes at points where they might come in contact with other wires. All other transformer-wires are supported upon double-petticoat glass insulators, and all dynamo-wires upon porcelain knobs.

Switchboard.

The switchboard is of narrow redwood boards, tongued, grooved and beaded, nailed on a framework of yellow pine, the latter supported on porcelain insulators to keep it dry. The switchboard outfit for one generator and one exciter consists of two 120 amp. fuse blocks, an A. C. field rheostat with a 25 amp. D. P. field switch with fuses, an exciter rheostat, one 150 amp. ammeter and a 200 amp. D. P. jaw-switch. From this switch the current passes to two 4-dynamo, marble switch-panels which are connected in multiple to the dynamo, and are each provided with two pairs of contact plugs. By means of these panels and of two 200 amp. dynamo-changing switches below them, any feeder can be operated from any dynamo which is connected to the switch-panels. Between each panel and its switch is a pair of 65-ampere Wurts shunt-wire fuse-blocks, each provided with an extra fuse and shunt which can be connected by inserting a plug, should it be desired to double the fuses during the run on account of overload or of weakness in the fuse. The remaining instruments on each feeder are a voltmeter, a No. 1 switchboard-converter and a 150 amp. type "E" compensator. When both feeders were run from one alternator, one voltmeter was connected to the generator and the other to the feeder, and in this way the amount of compensation could be watched.

The oil-transformers were tested before shipment with 20,000 volts between the line-coil and the core, and were then taken out of the oil and boxed. In order to expel any moisture which might have been absorbed by the insulation of the coils or have condensed on the cores during their long journey, the transformers were connected in two banks of ten each, the line-coils of each set being connected in series to the generator, which was run at a reduced speed, and the secondary coils each short-circuited on itself. The coils were thus gradually heated to a point somewhat above the boiling point of water, which at that elevation was

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about 201 deg. F. They were kept at this temperature for a short time and then paraffin oil of a special grade ("Diamond") was poured slowly into the boxes at the edges so that the coils would begin to absorb oil at their lower ends, and thus drive upward the air and volatile gases occluded by the insulation. The transformers were then again brought to their former temperature, which caused expansion and partial expulsion of the air remaining in the insulation. Some of the air would however collect under the insulation at the top of the coils, and had to be freed by mechanical agitation, produced by stirring the folds of insulation or by pounding on the boxes. The heat caused volatization of some of the lighter elements of the oil, these coming to the surface as bubbles, just as the air did at first, and the agitation was kept up at intervals until bubbles from this cause also were entirely eliminated.

The 20 transformers were then connected as they would be when in regular use, and the two terminals of the line-coils, which were to give 10,000 volts, were connected in series with one hundred 100-volt lamps, which were then brought to full candle power, showing that the transformers were all in good condition. A similar test was then made at Pomona at the end of the 14-mile transmission line running to that place, after which the transformers there were prepared for work in the same way as at the power-house, except that the grouping and initial voltage were changed.

Lines.

There are two transmission lines, one 13¾ miles long, which supplies Pomona, and another 28¾ miles long, which supplies San Bernardino. (See Fig. 4.) Each line consists of two No. 7 B. & S. gauge, hard-drawn copper wires. The joints in the wire are made with McIntire connectors. To further improve the joint, the ends of the wires were bent back side by side and soldered together. After the Pomona line was completed and the first ten miles of the San Bernardino line was put up, the supply of connectors ran out, and the regular telegraph joint was substituted. The conductivity was assured by soldering as before.

The wires are supported upon large double-petticoat flint-glass insulators designed for this plant. These insulators are of perfectly clear flint-glass, which gives a better surface-insulation than is attainable with any other kind of glass.

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It was at first proposed to use oil insulators. The reason they were not used was because the glass companies which had undertaken to furnish them, found on trial that they could not make them without considerable experimenting, which would have delayed the installation of the plant. This was no doubt fortunate, as the country through which the line passes is subjected to hot, dry winds which not only blow dust onto the insulators, but also inside them, and during the day the sun beats on the insulators until they become so hot that they nearly blister one's hands. If oil were used under these conditions it would soon evaporate and thicken, and become filled with dust. It would therefore seem undesirable to have used oil insulators in this case, or to

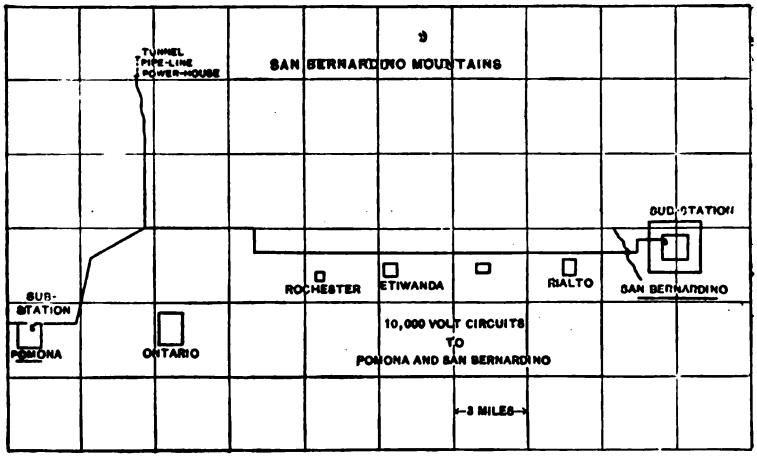

FIG. 4.—Route of Lines.

use them in any other until an increased voltage makes them necessary, and the transmission of greater amounts of energy over the circuits justifies the additional expense necessary to keep the insulators in good condition.

The two circuits are carried on the same pole line for 7½ miles. (See Fig. 4.) The inside pair of pins was used for the circuit to Pomona, and the outside pair for that to San Bernardino, until after the acceptance of the plant, but in anticipation of the installation of another generator, the Pomona circuit was changed to the right-hand pair of pins, and the San Bernardino circuit to the left-hand pair, to avoid the fluctuation in lights which would result from inductive interference between two independent circuits.

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Commercial lighting in Pomona was begun November 28th, 1892, and a telegraphic order was at once sent for another set of reducing transformers, to be used at San Bernardino, where the local circuits were already nearly completed. It was a condition of the franchise for the latter place that lighting should be begun before January 1st, and work was pushed rapidly on the transmission line, over 28 miles long, until it was finished. The order for transformers had, however, been given too late for them to be delivered in time, and it was decided to reduce the pressure at Pomona to 5,000 volts and to take to San Bernardino the half of the Pomona bank thus made available. In order to avoid the re-heating which would have been required had the transformers been dismounted for shipment, the latter were hauled to San Bernardino on wagons without springs, after the lids had been packed so that the oil could not splash out. The transformers reached their destination after midnight, and the next day, December 31st, they were connected to the transmission line for a few moments to see that the latter was all right, after which all the lights on the circuit were thrown on for the night.

When the new transformers arrived they were set up and heated in the same way as the others. The heating was continued night and day until complete, without interrupting the regular lighting service. The change of both circuits to 10,000 volts was made February 16th, 1893.

Sub-Stations.

The sub-stations at Pomona and San Bernardino are small brick buildings, one story high, with flat tin roofs and numerous windows. The Pomona building contains two rooms connected by a door near the switchboard. The front room is used as the office of the company, and the other as a transformer room. The 10,000-volt circuit enters over the door, and is connected directly to the bank of lowering transformers, no switches or other appliances being used on the high tension lines either there or at San Bernardino. The switchboard appliances are a Stillwell regulator, two 100-amp. marble fuse-blocks with double plugs and fuses; a 100-amp. jaw-switch, 150-amp. ammeter, compensating voltmeter, compensator and converter.

The San Bernardino sub-station is longer than that at Pomona, and is not divided by a wall. The transformers are placed in a

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row along a side wall, and along part of the end wall next the switchboard. The transformers near the switchboard heat the most. This is probably due to the slight drop in wiring between them and the more distant converters. During the first year of operation a little new oil was put into the converters about every four months to make up for that evaporated, but none of the old oil was drawn off. The switchboard apparatus is like that at Pomona.

The Stillwell regulator has long been recognized as a valuable adjunct to the central station operating a number of feeders of different lengths from a single dynamo. Its utility is still greater in a system of long-distance transmission in which the transmission circuits are supplied from one dynamo, as was the case in this plant during its first year of operation, since it is not practicable to install such a system so as to operate with small line-loss, and therefore means must be provided to compensate for the large differences in the pressure at the ends of the lines. The use of regulators at the power-house was impossible when but one bank of raising transformers was used for the two circuits. Even when it became possible by the use of separate banks of transformers, it was still undesirable because the attendant at the power-house would often have had to work both the regulators at once to properly compensate for changes in load, and his attention would have been required by the regulators at exactly the time he should have been free to attend to the generators. A regulator was therefore placed at each sub-station, as already stated. These are each of 2000 lights capacity and have a range of 10 per cent. up, and 10 per cent. down. This variation of 10 per cent. (100 volts) is divided into 14 equal parts, so that each step corresponds to 7.1 volts. The diagram (Fig. 5) was taken one Sunday, while using only 5000 volts, and shows the number of changes required during the evening at each station. The line marked "off" is the base line, and the divisions above and below correspond to the steps on the dial and show to what an extent the regulators were used to increase and decrease the pressure. This diagram shows how impossible it would be to furnish lights without using regulators, even on Sunday when the load is much smaller than on other days. It also shows that on that day the pressure at Pomona was being mostly reduced while that at San Bernardino at times (as at the point marked "very bad light") could not be sufficiently increased. This indicates that the pressure of the lowering trans-

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formers at one of the sub-stations should be changed so as to make the pressures at both more nearly equal, and thus increase the effective range of the regulators. In the present plant this is done by changing the number of transformers.

The distribution from both sub-stations is effected in the usual manner at 1000 volts for incandescent lighting, the only point of interest being, that a considerable number of Helios arc lamps are successfully used on the incandescent circuits.

Observations.

While in use, the transformers in the sub-stations give forth a continuous hum which depends for its tone on the number of alternations. This is an excellent indicator for the attendant, whose attention is instantly called to any change in the running conditions of the plant by the resulting change of tone. Its indications not only mark changes which are taking place and which can be detected on the voltmeter, but also give notice of coming changes before there is any other indication of them. It is thus possible to foretell a coming drop in voltage in time to use the regulator and thus keep the voltmeter needle perfectly still, though the voltmeter is a very sensitive instrument, and the regulator is often moved four or five notches. The hum often changes, however, without any corresponding movement of the voltmeter, but the sound is then somewhat different. At rare intervals the switchboard lights will suddenly change slightly in candle-power before any change is noticeable on the voltmeter.

It is noticeable that the needle will often stand for a time perfectly still on the center, and, on a slight rise in the hum, will start gently rising, never more than three-quarters of an inch, and then as the tone gradually becomes lower, slowly fall back to the center and stop without passing it. At other times the variation in hum is more sudden and the needle will rise and oscillate above the center. Again, the needle will oscillate equally about the center during a regular rise and fall of hum, its movement being apparently due to one impulse and not seeming to be modified by subsequent variations. There is no apparent change in candle-power of the lamps during the voltmeter changes noted. These notes were made while the plant was running at only 5,000 volts, but they were later confirmed when using 10,000 volts. During dry weather there is considerable intermittent oscillation of the voltmeter-needle without there

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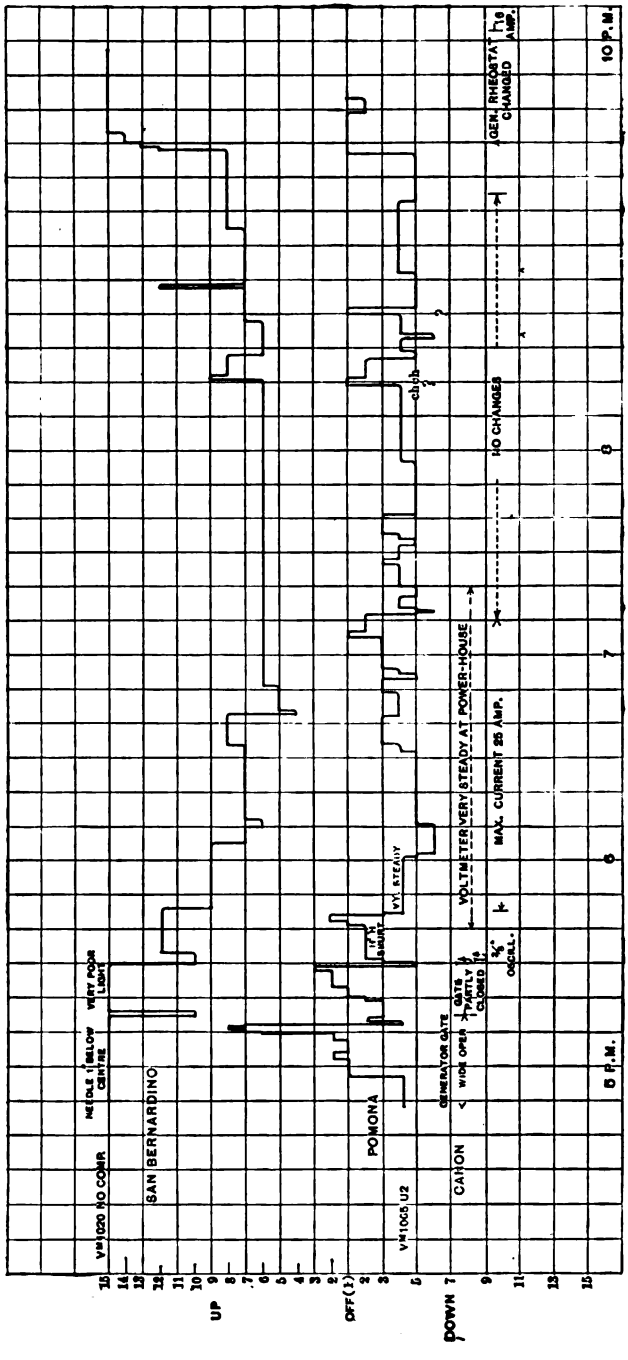

Fig. 5.—Diagrams Showing Use of Stillwell Regulators at Pomona and San Bernardino, with Notes of Simultaneous Conditions at Cañon.

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being any change in load or any other apparent cause, while in wet weather, the needle remains perfectly still for many minutes at a time, often for as much as half an hour. A possible explanation of this oscillation may be found in the presence of static charges on the line, due to atmospheric electricity. That the line is often heavily charged from the air, is shown by a number of observations. One afternoon a painful shock was obtained on touching the line at the canyon end, drifting clouds and a strong wind being noticed in the valley. Again, while using the telephone a report was heard in it so sharp as to cause momentary deafness. Later, after a moderate wind had been blowing for some time, loud reports were noticed on the telephone at long intervals. As the wind became higher the reports came oftener, and the intervals between the reports became shorter. It was evident that there was a discharge from the lines through the telephone (which was on a metallic circuit) and that it depended on the rate at which the wind blew. In order to get the strongest effect the two wires were connected in the usual way to the raising and lowering transformers, and one side of the telephone connected to one wire. On connecting the other side of the telephone to ground a sharp report was heard, and on maintaining the connection there was a sound as of steam escaping at a distance, with intermittent and very faint crackling. If the ground contact was made slowly, there was a bright spark before the metals touched, and a loud report. If the fingers were interposed a smart shock was received. By making and breaking the ground connection rapidly, the line was prevented from accumulating a heavy charge, and no spark was visible, though a faint crack was heard. If a slight space was left between the telephone wire and the ground, a spark occurred at fairly regular intervals, and when the space was lessened the sparks became smaller and more frequent. When the wind lessened, the sparks and reports became almost imperceptible, but on the wind becoming strong and blustery a large spark was again obtained. When one line wire was disconnected from the transformers at Pomona the effect obtained from grounding that wire was less, owing to the reduction in capacity.

These observations, which were made on the Pomona circuit during hot, dry and cloudless weather, show conclusively that the lines were heavily charged by the action of the wind. The wind no doubt blows electrified air and dust against the wires,

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the latter thereby accumulating a static charge with a rapidity which we have seen depended on the speed of the wind.

Some curious conditions met with in the operation of the plant are shown in the ampere curves in Fig. 6, which were taken during very wet weather. Taking the maximum load measurements at 7 P. M. for March 14th and 8th, we note that the total apparent energy delivered by the sub-stations is 73 per cent. and 75 per cent., respectively, of that delivered by the generator, while for a smaller load at 9 P. M. the respective percentages decrease to 47.6 per cent. and 48.6 per cent. in spite of the fact that the apparent energy delivered by the generator is in the latter case only half as great as in the former. These results are due to changes in the angle of lag caused by changing the load.

In the Cañon curve of March 8th, the load at 9.30 P. M. is seen to have increased considerably, although the sub-station loads were decreasing. This increase was due to the fact that the rain which had previously ceased to fall at Pomona, began again.

Tests.

The electrical resistance of the Pomona circuit is 74.9 ohms and that of San Bernardino 156.4 ohms at about 90 degrees F.

The insulation resistance of the circuits varies from far beyond the limits of an 11-megohm bridge in dry, hot summer weather, to as low as 0.65 megohm during light rain. The latter value is that obtained with the two San Bernardino wires in series, and represents an insulation-resistance per mile of over 37 megohms. On a clear, sunny day the insulation-resistances of one Pomona wire and of one San Bernardino wire were respectively 11 megohms and 5½ megohms, which are in the exact relation which would be expected.

The lines cannot be tested for grounds or for continuity with a magneto bell, as their capacity is such that the bell will ring loudly when the wire is perfectly insulated and the circuit open. This capacity also prevents the use of the ordinary converter test for line leakage, as the lamp on the secondary will burn as though there were a ground even when the line is perfectly clear. By adding lamps, however, the light may be cut down until the last lamp added extinguishes them all. This would not occur if the light of the first lamp was due to a difference of potential on the primary caused by a ground, as then the added lamps would be-

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come as bright as the first. The primary current is thus seen to be limited, and to be due to the capacity of the line. If the proper number of lamps has been added, to just secure darkness when the line is known to be free from grounds, the converter

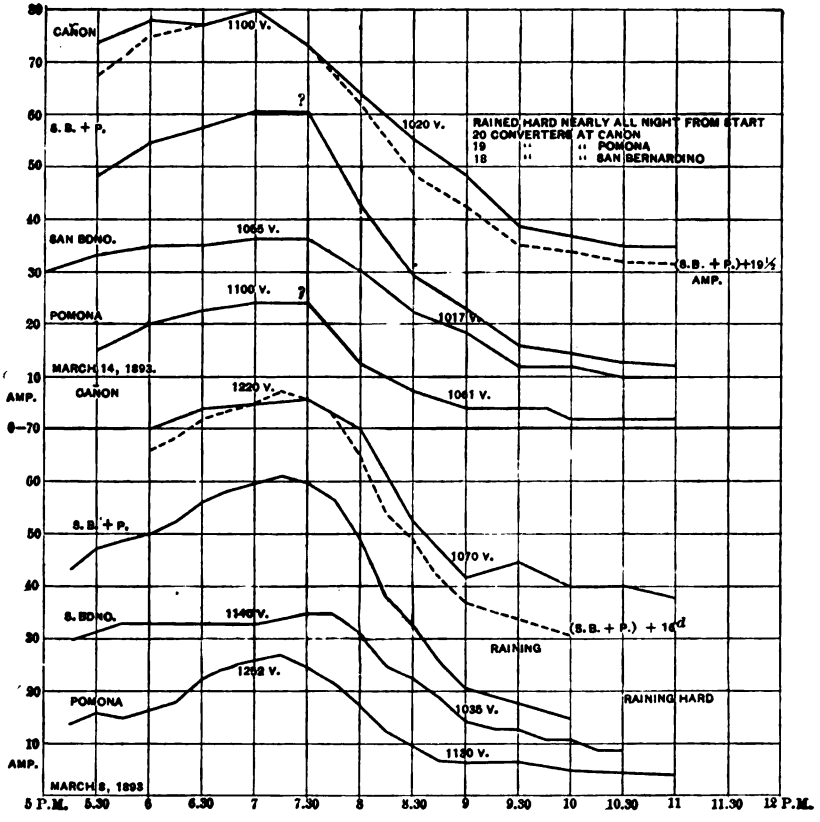

FIG. 6.—Ampere Curves. Showing Excess of Cañon Load over the sum of Pomona and San Bernardino Loads, and also Decrease in Difference between Cañon Load and this Sum as the Cañon Load Increases.

Notes on March 8th. Raining in afternoon and nearly all night at Pomona. Snowing throughout canyon and a mile or so outside of mouth of canyon. 8 inches of snow at power-house, covering insulators and cross-arms completely. 1 inch of snow on wires. Snow damp and clinging. No wind. 20 converters at Cañon, 19 at Pomona and at San Bernardino.

may be used to show grounds on that line, since the presence of a ground will cause all the lamps to brighten. The line test should only be made after ascertaining with one lamp that the generator is not grounded, as otherwise the leakage cur-

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rent for the greater number of lamps might burn the insulation of the generator. A very good example of Prof. Fleming's "condenser effect" was met with in the summer of 1893, while the engineer was trying this converter test for measuring line leakage. The primary of a 1000—100-volt converter was connected between the ground and one terminal of the generator, the other terminal of the latter being connected to one wire of the Pomona circuit. The resulting secondary pressure

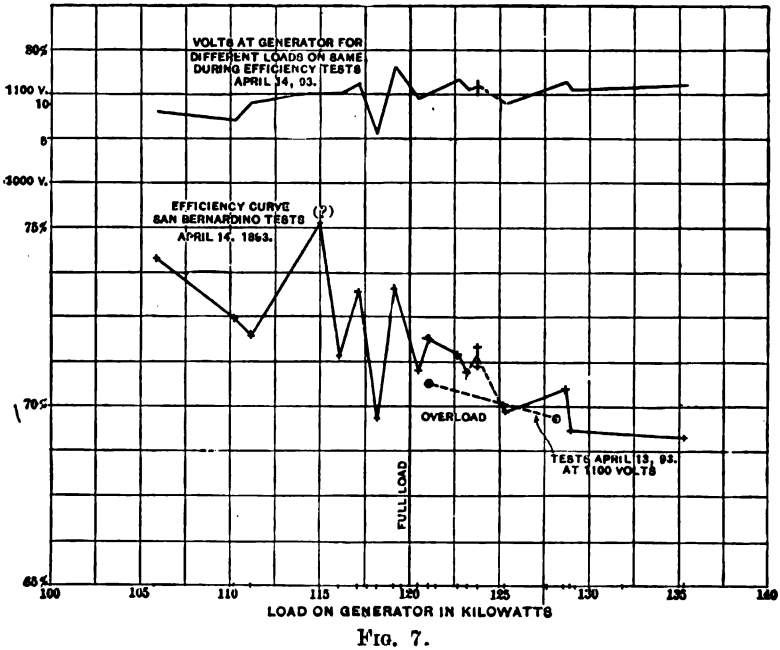

FIG. 7.

was 30 volts, which made one lamp burn dimly. When ten lamps were turned on, the pressure dropped to 14 volts. When all lamps were turned off the pressure became ten times as great, or 140 volts. One generator brush was then raised, and the second wire of the circuit was connected to the first. On completing the circuit again there was a sudden flash on the armature, followed by a crackling noise and a brush discharge which lasted until the circuit was broken. The Pomona wires were then disconnected from the dynamo terminal, which was left free. With this arrangement faint sparks and a glow were noticed, as

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though the armature winding were grounded on the core, but a Wheatstone bridge test showed an insulation resistance of over 10 megohms. Since then the machine has been used regularly and has not broken down, so it is evident the spark must have resulted from a sudden increase of the potential of the armature winding above that of its core, which latter was permanently connected to earth.

This sudden increase may be explained as follows. On closing the circuit the condenser formed by the line and the earth began to discharge through the metallic circuit afforded by the armature and converter windings, but the self-induction of this circuit checked the discharge so quickly as to produce an excessive pressure which could only be relieved by the discharge taking place through the insulation of the armature-winding to the grounded core, which is what happened.

A similar test was made on the San Bernardino wires in the previous January during dry weather, the only change being that the single lamp was not turned off. With only one wire connected, one 16 C. P. lamp came nearly to candle-power. On connecting the second wire to the first (at San B.) the lamp burned at full candle-power. Ten lamps (the full load) were then put on the converter and burned dimly. As they were turned off one by one, the others brightened until the last lamp lighted up as before. This test did not cause any discharge on the armature, in spite of the fact that the circuit was twice as long and the capacity thus twice as great. The probable explanation of this is that the inductive resistance of the converter was not so great as in the other case, on account of the single lamp being left burning. It is also possible that the breakdown in the other test was assisted by the presence of copper dust on the winding.

A comparison between the ammeters used at Pomona and San Bernardino showed that for readings above 67½ amperes the San Bernardino instrument read higher than the other. As there was no reason for considering one instrument more accurate than the other, and no way of telling which was right, the San Bernardino readings taken during the test were reduced to the average of simultaneous readings on the two instruments.

A short test of the Pomona circuit was made on April 11th, the results of which are given in Table I.

A preliminary efficiency test on the San Bernardino circuit was made April 13th, 1893, with the results shown in curve in Fig.

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7. In this, as in all the other tests, a variable load was obtained by the use of a water resistance.

An efficiency test of the San Bernardino circuit lasting five hours, during which the generator was kept at full load or overload, was made April 14th, 1893. The voltage at San Bernardino during the tests was measured with a Weston portable voltmeter. Readings were taken every fifteen minutes, and the efficiencies and the corresponding voltages for different loads are

TABLE I.

EFFICIENCY TESTS. POMONA CIRCUIT.

pril 11th, 1893.

Cañon (20 Converters).			Pomona (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
120	1100	132	105.85	919	97.28	73.7
118.5	1100	130.35	105.85	945	100.01	76.73
119.5	1100	131.45	107.4	929	99.78	75.9

TABLE II.

42½ MILE TRANSMISSION TEST. CIRCUIT TO SAN BERNARDINO, BY WAY OF POMONA, 85 MILES.

May 2nd, 1893.

Cañon (20 Converters).			San Bernardino (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
95	1120	106.4	80.75	847	68.4	64.28
96	1130	108.5	78.8	865	68.16	62.82
100	1200	120.0	81.7	893	72.96	60.8

plotted in Fig. 7. The most prominent feature of this efficiency curve is its irregularity. This is, however, satisfactorily explained by referring to the curve of generator voltage, on which it is seen that the high efficiencies correspond to high voltages, and *vice-versa*.

It will be noted that the apparent efficiencies shown by the preliminary test at San Bernardino agree very closely with the results of the long efficiency test there. On calculating the apparent efficiencies for different loads from data obtained by lab-

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oratory tests, and comparing them with the measured apparent efficiencies, it is found that they agree within three or four per cent. This very close agreement is exceedingly gratifying, particularly when we consider that the tests of the plant were made with ordinary commercial instruments, and that the laboratory tests were made about a year before the commercial tests.

An interesting and unique test was made May 2d, 1893, by connecting the Pomona line wires in series with the San Bernardino circuit, and transmitting about 100 H. P. to San Bernardino by way of Pomona. The length of the circuit was 85 miles, and the distance of transmission 42½ miles. This is the greatest distance yet covered by any transmission since the Frankfort experiments. The measurements are given in Table II. The apparent efficiencies are much lower than those indicated by calculations, as in the latter no account was taken of the capacity and inductance of the circuit. The voltage of the generator as measured is about 5 per cent. above that calculated, and the amperes measured, notably exceed the amperes calculated. These results are attributable to the introduction of the Pomona loop, which added both capacity and inductance.

In order to reduce the cost of operation, the San Antonio Company first dispensed with the sub-station attendant at Pomona after 11 P.M. This they did sometime before the acceptance of the plant, after assuming the responsibility for any damage which might result. No trouble occurred and, after the acceptance (May 6th, 1893,) the same plan was put in operation at San Bernardino. After working in this way for several months, the Pomona station was started in the afternoon and then locked up until the next morning. This arrangement was made possible by running the generator so that the pressure would be right at Pomona, the pressure at San Bernandino being kept right by the attendant with the Stillwell regulator.

In January, 1894, another 120 K. W. generator was installed with an equal capacity of oil transformers, and the Pomona and San Bernardino circuits are now each operated from separate generators with separate banks of transformers at 10,000 volts. Since this change the San Bernardino attendant has also been dispensed with, and the book-keeper starts up in the afternoon and then locks up the station for the night, as at Pomona. The voltage of the lamps on each circuit is regulated by the engineer at the power-house, the generator pressure necessary at different

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loads to keep the lamps at the proper brilliancy being automatically indicated by the compensating voltmeter on each circuit. Thus after the plant is started the engineer has sole charge.

The following associate members were elected at the meeting of Council held at Niagara Falls, June 27th, 1895.

DANIELSON, ERNST,	Consulting Electrician, 16 Scheele Gatan, Stockholm, Sweden.	Elihu Thomson. E. W. Rice, Jr. H. M. Hobart.
GHERARDI, BANCROFT, JR.,	Assistant in the Engineering Dep't Metropolitan Tel. & Tel. Co.; residence, 6 East 34th St., N. Y. City.	W. L. Bliss. Sam'l Sheldon. A. L. Riker.
HESSENBRUCH, GEO. S.,	Assistant Electrical Engineer Accumulatoren Fabrik, Hague, Germany; 3 Head Place, Boston, Mass.	B. C. Paddock, Jr. F. Wm. Erickson. R. W. Pope.
HORNSBY, HARRY H.,	Electrical Inspector, City Hall; residence, 1801 Barry Ave., Chicago, Ill.	C. C. Haskins. B. J. Arnold. L. K. Comstock.
HUGUET, CHAS. K.,	Instructor in Electrical Engineering, Tulane University; residence, 1216 Carondelet St., New Orleans, La.	Brown Ayres. A. L. McRae. A. F. McKissick.
JEHL, FRANCIS,	Representative, F. Hardtmuth & Co., 60 Liberty St., N. Y. City.	Wm. J. Hammer. R. W. Pope. Francis R. Upton.
MERRILL, EDWARD B.,	Principal and Instructor in Electricity, etc., at the Toronto Technical School; residence, 38 Cecil St., Toronto, Ont.	T. R. Rosebrugh. John Langton. W. M. Rutherford.
ORMSBEE, ALEX. F.,	Electrical Engineer; residence, 183 Joralemon St., Brooklyn, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
PEIRCE, ARTHUR W. K.,	Instructor in Electrical Engineering, The Colliery Engineer Co., Scranton, Pa.	J. Hally Craig. Geo. Cutter. Wm. H. Donner.
PRICE, EDGAR F.,	Electrician, Newark & South Orange Railway Co.; residence, 16 Rector St., Newark, N. J.	Philip A. Lange. L. A. Osborne. H. M. Wharton.
SAWYER, FRED. W.,	Student, Worcester Polytechnic Institute; residence, 42 Harvard St., Worcester, Mass.	A. S. Kimball. R. W. Pope. Edw. Caldwell.
TORCHIO, PHILIPPO,	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane St., N. Y. City.	Wm. J. Hammer. E. A. Leslie. J. W. Lieb, Jr.
YOUNG, CHARLES I.,	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.	A. J. Wurts. Chas. F. Scott. L. B. Stillwell.

Total, 13.

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 27th, 1895. President Duncan in the Chair.

ALTERNATING CURRENT CURVES.

BY CHAS. E. EMERY, PH.D.

§ 1. The sine curve used to represent the variations in magnetization, electromotive force and current, has the advantage that the same curve is applicable for each of the three phenomena and that the changes in sign and direction are repeated periodically, so that differences in the phase relations of the different curves may be conveniently represented by the angles between several radii of a generating circle. The resulting trigonometrical functions have enabled elaborate general investigations to be successfully carried on, and satisfactory solutions have been obtained, applicable strictly only to the conditions assumed, but which indicate the nature of the variations which would result under different conditions.

§ 2. With sine curves the watts may be obtained from the current and electromotive force and the difference in phase between the same, but for other than sine curves this method is strictly applicable only when the current and E. M. F. are in phase, though very valuable practical results have been obtained by special methods involving "equivalent sine curves" and a modified or "equivalent angle of lag." It is therefore desirable to develop a general system for formulating and integrating the values of the "instantaneous watts" applicable to curves of different shapes which will include an approximate sine curve as a special case. Such a system should avoid the necessity of using "equivalent" values and enable the distortions of alternating current curves to be explained directly, by formulating the conditions which produce the same instead of considering arbitrary "harmonics."

§ 3 The following is a statement of the principal require-

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ments of curves which will fairly represent observed phenomena:

I. The curve used should at least so resemble the experimental curve that, when not superimposed, it will appear identical to the eye on the small scale used for illustration.

II. It is desirable that the same function represent curves greatly differing in appearance, such for instance as those approximating rectangular or triangular shapes or the sine form.

III. The function should be of a kind that the resulting equations, showing instantaneous values of electromotive force and current, can readily be multiplied together to show instantaneous watts.

IV. The original and all resulting equations should be readily integrated by *inspection* so that the total watts or other desired quantities can be obtained directly from such equations.

V. The function and resulting equations should be of such kind that further conditions may be imposed upon conditions already embodied, and thereby the influence of hysteresis, and other phenomena less striking but more important, be expressed in the form of equations and resulting curves, and the influence of one condition upon another studied mathematically in connection with observed distortions of experimental curves, without changing the general features of the equations so as to prevent integration by inspection as previously stated. The object of such investigations should be to bring direct current formulæ and alternating current formulæ for momentary values into the same shape, so that the various conceptions will be simplified and the modifications appear to be due only to the new conditions imposed.

§ 4. The writer has developed and applied a simple, well known algebraic function which appears to satisfy the first four of the five general requirements above stated, and has made progress with the very many important problems involved in the fifth requirement, but since delay in obtaining complete results is inevitable, it has been thought desirable to present in detail the distinctive features of the method, so far as satisfactorily developed in order that it may become familiar to others working in the same line, and perhaps have the effect, by the introduction of a number of workers, to hasten the consummation of the desired end.

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§ 5. The details of the method will be much more readily comprehended by a preliminary elementary presentation along similar lines of matters already understood by those familiar with the subject.

§ 6. The electromotive force in a conductor under the influence of alternating magnetism is generally stated to be at any instant, proportioned to the rate of change in magnetic induction, which is equivalent to the rate of change of magnetism or in the number of magnetic lines of flux included at the moment in the circuit.

§ 7. In Fig. 1, *e* represents a curve of alternating E. M. F. and *m* the corresponding curve of alternating magnetism. A complete period is represented by four divisions, those included between ordinates *a a*, for instance, laid off on the axis of abscissa x x. Measurements to the right from an origin to be fixed by the conditions are herein to be considered plus, and those to the left, minus, as customary in geometrical delineation; the variations being as if an *ordinate to mark the time were moved clockwise across the curves* proportionally to the time. The ordinates of the curve *e* represent the mometary values of the variable E. M. F., and the number of lines flowing momentarily in the magnetic circuit is represented by the ordinates of the curve of magnetization *m*.

§ 8. It is well known that the rate of change of a variable ordinate of a curve is represented by the tangent to such curve, and the equation of the tangent is the differential of the equation of the original curve, so, since the curve *e* represents the rate of change of the ordinates of the curve *m*, the equation of the curve *e* is the differential equation of the equation of curve *m* and the ordinates of curve *e* represent proportionally the values of the tangents of curve *m*. When the value of the magnetization *m* is zero, as at *a*, the tangent to the curve is a maximum and the ordinate of the curve *e* of E. M. F. is also a maximum. Again, when the magnetization is a maximum, as at ordinate *b*, the tangent to the curve is zero and the E. M. F. shown by curve *e* is also zero.

§ 9. The curves *m* and *e*, as drawn, are based on sine functions and are, therefore, similar and equal, but located one-quarter phase apart along the time axis. If any other than a sine function be employed, the two curves are dissimilar, but the equation of *e* will still be in the differential equation of the equa-

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tion of curve m, and the two curves be at a quarter phase the same as before.

§ 10. Sine curves for rectangular coordinates, Fig. 1, may be considered generated by moving a time ordinate uniformly from left to right and revolving clockwise at the same time a generating radius r, Fig. 1a, uniformly about a center o and plotting the ordinates of the two curves in Fig. 1 from the sines and cosines of the arcs through which the radius r is moved in Fig. 1a. In these figures, as drawn, the radius r, Fig. 1a, should be moved through 90° in the same time that the imaginary time ordinate is moved one division in Fig. 1. The method of revolving two generating radii fixed 90° apart will evidently give the same result as by using the sine and cosine, but the latter is required in the mathematical treatment of the subject.

§ 11. If for sine functions θ = the angle through which the generating radius is moved uniformly, or proportionally to the

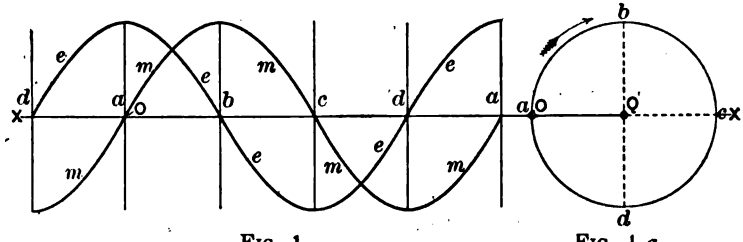

FIG. 1. FIG. 1 a.

time, the fundamental equation applies to the value of the magnetization and we have

$$y = \sin x = m = \sin \theta. \tag{1}$$

$$\frac{d\,y}{d\,x} = \frac{d \sin \theta}{d\,\theta} = e = \cos\ \theta. \tag{2}$$

§ 12. The equations show, that at any particular moment, the ordinate of a sine curve of magnetization simply equals the sine of the angle through which the generating radius r has been moved, and that the corresponding ordinate of the curve of E. M. F. which equals the tangent of the curve m, plotted in a system of rectangular coordinates, Fig. 1, is equal to the cosine of the angle through which the generating radius has been moved, thereby confirming the previous statement.

§ 13. Sine curves plotted from Eqs. (1) and (2), or as described, reverse at regular intervals and develop equivalent branches of what may be termed a sinusoidal curve. If it be at-

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tempted to use any other than a sine function as a basis of a representative curve, such curve can only be applicable between limits. Evidently, however, the positive and negative branches of any alternating curve are, if symmetrical, in one sense dupli cates of each other and merely reversed and changed in position. A curve based on any function may be satisfactorily studied between the limits of tangent zero and tangent maximum which corresponds to a quarter period for alternating current curves, and an equation of such curve will give positive and negative branches which jointly extend through half a period. Evidently such branches can graphically be reversed and combined so as to form a curve reversing in direction regularly like a sinusoidal curve, and it is not necessary for accuracy to express the whole operation mathematically, as all the elements of the combined curve required for our purpose are included in one of the parts developed from the formula between the limits for which it is applicable.

§ 14. In the equations hereinafter developed, a quarter period is represented by the symbol s, the value of which can be changed at will, but in the calculations, is for simplicity made equal to 10. In the formulæ, fractions of s are represented by x, so in Eqs. (1) and (2), for $s = 10$.

$$\theta = 9\,x. \tag{3}$$

§ 15. For convenience, a maximum diagram height of 10 has also been selected and corrections are to be made for actual values by numerical coefficients. The several curve values are distinguished as "diagram magnetization," "diagram E. M. F." and "diagram current," and provision made to reduce these quantities to actual magnetization, E. M. F., and current, in practical units, without intermediate expression in "absolute" measurements, which are evidently one-tenth of the diagram units.

§ 16. With the sine function it is convenient to consider a base of $2\,\pi$ or one complete period; a to a, Fig. 1, for instance, For the equations herein developed applicable to various curves of very different shapes, a base of one-quarter period is employed, which is extended to one-half period by the reversals due to negative values. It should be borne in mind at the outset that the base has nothing to do with the results. In all representative curves the value of the ordinates is stated in terms of the base and apparently of the time which the base represents, but actually the time is not considered in this way, as the E. M. F. depends upon the

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"frequency" or number of complete cycles per unit of time which is always introduced as an arithmetical factor independent of the function. It is, therefore, necessary to divide out the base, whatever system is adopted, before multiplying by the factor of correction. In some alternating current formulæ this precaution does not appear to have been taken.

§ 17. The general equations are based on the simple algebraic function,[1]

$$y = A_1 x^u. \tag{4}$$

§ 18. In this and subsequent equations

y = in general the variable ordinate of the curve considered.

x = the variable abscissa.

x_1 = the length of base between limits of integration.

s = one-quarter the length a, a, Fig. 1, or a quarter period along a time axis, but not to be considered as time, for reasons explained in § 16. Usually s is made equal to 10.

u = an arbitrary partial exponent, constant for a particular series of solutions.

v = the same for equations of series I.

A_1 = a general constant.

$(f\,A)$, read function of A, = a factor introduced to reduce ordinates of the curve m to actual magnetic lines of flux.

A = a constant representing the approximate value of $(f\,A)$ for the particular conditions considered, the modification being necessary to obtain a solution of the equation.

A_2 = a constant of reduction providing for the number of turns, arithmetical constants, etc., necessary to reduce ordinates of curve e to actual values of E. M. F. in practical units.

A_3 = a constant of reduction to provide for resistance, inductance, etc., in reducing E. M. F. to current.

1. Some of the remarkable properties of this function have already been pointed out by the author in a paper on "Rational and Empirical Formulæ showing the Relation between the Magnetomotive-Force (H) and the Resulting Magnetization (B)," TRANS. AM. INST. EL. ENGRS.: June, 1892, in which was given for consideration some reasons why magnetic lines should be considered as a translatory movement of an ether. (Such a theory is simply suggestive. It requires not only that the transverse current of Maxwell be either identified with or act as the cause of the magnetic lines, which may in time be accepted, but it also requires that the experiments of Herz be referred to causes other than those stated, for which there is as yet no reason except the possible errors of indirect methods).

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$B = AA_2$

$D = AA_2\,A_3$

m = diagram magnetization or the length of the ordinates of a diagram or curve representing momentary magnetization.

$M = \frac{Am}{s}$ = actual magnetization or total nmber of magnetic lines momentarily flowing in the circuit considered.

e = diagram E. M. F. or lengths of ordinates on diagram representing E. M. F.

$E = \frac{B\,e}{s}$ = actual E. M. F. above zero in volts.

c = diagram current or the length of the ordinates of a diagram representing current.

$C = \frac{D\,c}{s}$ = actual current in amperes.

$w = e\,c$ = momentary diagram watts or the product resulting from multiplying momentary diagram current by momentary E. M. F.

G = integral of diagram watts between limits to be mentioned.

w_1 = average diagram watts by integration.

$W = \frac{B\,D\,w_1}{s^2}$ = actual watts in practical units.

§ 19. From the function shown in Eq. (4) two series of equations are developed, viz: Series I with origin at zero of curve of E. M. F., and Series II with origin at zero of curve of magnetization. For Series I the resulting curves do not as closely resemble practical curves of magnetization and E. M. F. as those of Series II, but both are given to show the remarkable properties of the underlying function.

§ 20. For Series I, using v as the partial exponent we obtain preliminary values distinguished by sub. 1 as follows:

$$e_1 = \frac{d\,y}{d\,x} = x^v, \tag{5}$$

in which form the origin must be at zero of E. M. F. or at ordinate d, Fig 1. Integrating we have

$$m_1 = y = \frac{1}{v+1}\left(x^{v+1} + C\right) = -\frac{1}{v+1}\left(s^{v+1} - x^{v+1}\right) \tag{6}$$

The value of the constant of integration C is readily determined from the condition that when $y = o$, $x = s$.

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§ 21. For Series II. we obtain preliminary values as follows:

$$e = \frac{d\,y}{d\,x} = s^{u} - x^{u}. \tag{7}$$

Integrating we have:

$$m = y = s^{u}\,x - \frac{x^{u+1}}{u+1}. \tag{8}$$

In Eq. (8) the constant of integration has been omitted, as the origin remains in the same place as in Eq. (7).

§ 22. It will be observed that the values of the ordinates are shown in terms of the maximum base s. In the calculations herein, s is made equal to 10, though the symbol is preserved to permit a ready change of base. The maximum ordinates vary in the four equations above given, so, for convenient practical application, we divide through by the maximum ordinate of each, and multiply by s, so that the ordinates as plotted and as shown by the following equations are in terms of s or ordinarily in a scale of 10. We then have the following:

§ 23. Series I. for Final Equations of Curves with Origin at Zero of E. M. F.. From Eqs. (5) and (6).

$$e_1 = \frac{1}{s^{v-1}}\,x^{v}. \tag{9}$$

$$m_1 = -\frac{1}{s^{v}}\left(s^{v+1}\,x^{v+1}\right). \tag{10}$$

§ 24. Series II. for Final Equations of Curves with Origin at Zero of Magnetization. From Eqs. (7) and (8).

$$e = s - \frac{x^{u}}{s^{u-1}}. \tag{11}$$

$$m = \frac{u+1}{u\,s^{u}}\left(s^{u}\,x - \frac{x^{u+1}}{u+1}\right). \tag{12}$$

§ 25. If in the equations of Series I., $v = 0$, the curve of E. M. F. or e is, as shown in Fig. 2, a rectangle, and the curve of magnetization m a triangle, the phase relations in all cases being as described for Fig. 1.

§ 26. If in Series I., $v = 1$, the curve e, as shown in Fig. 4, becomes a triangle and the curve m an ordinary parabola. The parabola very much resembles a sine curve when one is not superimposed upon the other. See § 31.

§ 27. Referring to Fig. 3, for which in Series I, $v = 0.5$, it will be seen that as v increases from 0 to 1 the curve e becomes pointed with rounded sides like the point of an acorn, and the

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curve m, though retaining the rounded top, approximates the shape of a triangle as the value of v approaches unity. For $v = 0.75$, however, m is practically a sine curve, though the corresponding curve e retains the sharp point.

§ 28. As v becomes greater than unity the curve of E. M. F. is

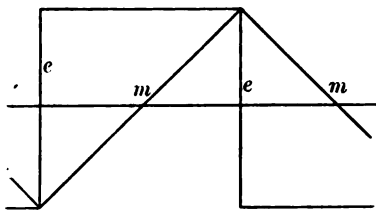

FIG. 2.—Series I, $v = o$
Series II, u = Infinity.

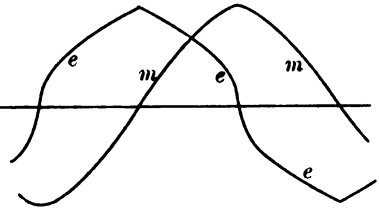

FIG. 3.—Series I.
$v = 0.5$.

in cusp form, viz: has a sharp point with hollowed side, and the curve m is broadened at the top, so that the curves resemble those shown in Fig. 5.

§ 29. If in Series II, $u = 1$, as shown in Fig. 4, the curve of E. M. F. or e becomes a triangle and the curve of magnetization m a parabola, showing that the values for partial exponent u or v = unity are for both series of equations identical.

§ 30. As shown in Fig. 5 for which $u = 0.5$ in Series II, for values of u between unity and zero, the curve e takes a cusp form and the curve m a rounded form.

§ 31. If in Series II $u = 2$ both curves e and m, as shown in

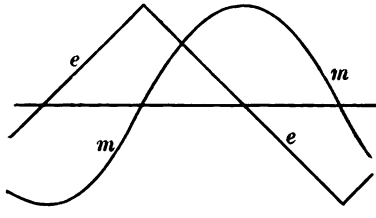

FIG. 4.—Series I, $v = 1$.
Series II, $u = 1$.

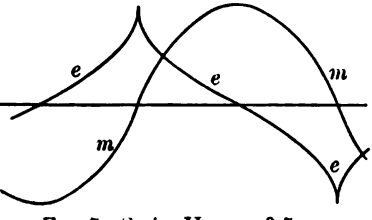

FIG. 5—Series II. $u = 0.5$.

Fig. 6, approach the sine form represented in dotted lines, the curve e being a parabola slightly greater in area than a sine curve and the curve m consequently of slightly less area than a sine curve.

§ 32. By using a fractional exponent, both curves can be

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brought still closer to the sine form. For $u = 1.781$ in Eq. (11) the square root of the mean square of the ordinates of the resulting curve e is 7.071 or the same as for the sine curve. The two curves being derived from different functions, cannot absolutely coincide, but the differences are so slight that to find them, the values must be extended to several decimal places, and, in plotting, the curves seem identical.

§ 33. If in Series II, the value of u be still more increased, the curve of magnetization m rapidly approximates the shape of a triangle and the curve e of E. M. F. approximates a rectangle, so that doubtless for $u =$ infinity, the curve would take the form shown in Fig. 2 for Series I, $u = 0$.

§ 34. The change above indicated is so rapid that for $u = 6$ in Series II, as shown in Fig. 7, the curve e has already taken the general shape of a rectangle with well-rounded corners, and the curve m the general shape of a triangle with rounded point. The curve e resembles closely the curve of electromotive force given by a dynamo from which armature reaction has been eliminated, as shown in a recent paper,[1] and the corners may be made still sharper by increasing the value of u.

§ 35. Unsymmetrical curves based also on $u = 2$ in Eqs. (11) and (12), Series II, are shown in Fig. 8. These curves are plotted with the same values of the ordinates as in Fig. 6, but the portion of the curve showing decreasing magnetism and increasing E. M. F. is plotted in a distance less than a quarter period, and the remainder of the curve in a distance greater than quarter period, so that the sum of the bases equals one-half period. These curves show that the phase relation of curves m and e may be changed simply by the shape of the curve m of magnetization. The plus and minus branches of this curve must be similar and of equal area, but the change of magnetism and of electromotive force during the increase of the latter need not be at the same rate as during the decrease.

§ 36. It will be observed that this very large variety of curves is finally derived from two simple algebraic equations for each series, viz.: For Series 1, Eqs., (9) and (10) § 23, and for series II, Eqs. (11) and (12), § 24. The first equation of each series is the differential equation of the second equation of that series,

1. Prof. H. J. Ryan and Mr. M. E. Thompson on "A Method for Preventing Armature Reaction," TRANS. AM. INST. EL. ENGRS., p. 84 *ante*.

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but the integration required to pass from the first to the second is already performed, the equations are complete and may be utilized at once by simply substituting numerical values.

§ 37. To obtain the watts, it is first necessary to know the elements of a curve representing the momentary current and the phase of the current in relation to the machine E. M. F. Methods based on the resistance, inductance and capacity of a circuit have already been employed to determine the phase relation of the current and the impressed electromotive force, when distribution caused by hysteresis, etc., was not considered, and as the present paper is confined to the explanation of a method of developing certain equations and ascertaining from those of E. M. F. and current the work done in watts, such purpose may be accomplished by assuming that the current curve is of the same form as the curve of E. M. F. as is customary, and developing a method to determine the influence of changes of phase, with the under-

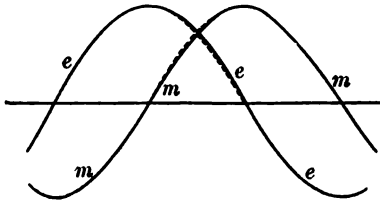

FIG. 6.—Series II, $u = 2$.

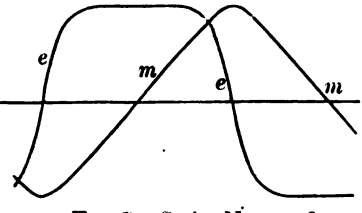

FIG. 7.—Series II, $u = 6$.

standing that for the purposes of this paper the phase angles are to be ascertained by methods at present in vogue.

§ 38. It is assumed as evident that the work derived from an alternating electric circuit for a particular apparatus must equal the product of the momentary E. M. F. at the main terminals and the momentary main or primary current flowing through such apparatus, which puts the calculations for momentary values on the same basis as for direct current. In Fig. 9 the ordinates of the curves e and c are intended to show the momentary values of the machine E. M. F. and of the primary current respectively. The ordinates are plotted in the scale of 10 and are to be corrected finally by arithmetical coefficients given in § 18. According to our conception that the time development is illustrated by an ordinate moving positively or to the right, the phase of the current c is behind that of the E. M. F. e because the maximum value of the former is reached later. The distance

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along the time axis $O\,N = k$ is called the difference in phase, which has a maximum value s and is expressed in the same scale. The difference of phase referred to generating radii, as in Fig. 1a, equals "the angle of lag," the value of which is $\varphi = k \div s \times 90°$.

§ 39. When $k = 0$ the current and electromotive force are in phase with each other, so that $w = e\,c = e^2$. Integrating the squares, either of the value of e in Eq. (11) or by substitution in Eq. (23) hereafter developed and dividing by the maximum ordinate, we have the mean square which is the value w_1 of the watts with e and c in phase. The square root of this, designated $\sqrt{\text{mean}^2}$, gives the effective voltage or current for curves of different forms.

§ 40. The mean square values for all of the representative curves developed, depend entirely upon the variable exponent, and are connected with the same by a very simple relation. The general equation is:

$$\sqrt{\text{mean}^2}\, e = \left(\frac{1}{s}\int_0^s e^2\, d\,x\right)^{\frac{1}{2}}. \tag{13}$$

For e_1 in Eq. (9).

$$\sqrt{\text{mean}^2}\, e_1 = \left[\frac{1}{s}\int_0^s \left(\frac{1}{s^{v-1}}\, x^v\right)^2 d\,x\right]^{\frac{1}{2}} = s\left(\frac{1}{2\,v+1}\right)^{\frac{1}{2}}. \tag{14}$$

For e in Eq. (11).

$$\sqrt{\text{mean}^2}\, e = \left[\frac{1}{s}\int_0^s \left(s - \frac{x^u}{s^{u-1}}\right)^2 d\,x\right]^{\frac{1}{2}} \tag{15}$$

$$= s\left(1 - \frac{2}{u+1} + \frac{1}{2\,u+1}\right)^{\frac{1}{2}}.$$

§ 41. The average diagram watts w_1, § 18, for e and c in phase are represented by the square of the mean^2 value, hence for a sine curve, or the substantially equivalent curve for which $u = 1.781$, mentioned in § 32, $w_1 = 7.071^2 = 50$ out of a maximum of 100 which would be obtained if a rectangular curve of E. M. F. were possible.

§ 42. If for the present investigation we assume $u = 2$ in Eq. (11), the resulting curve e, as shown in Fig. 6, § 31, is a parabola, which, as stated, has a little greater area than a sine curve, the $\sqrt{\text{mean}^2}$ value being 7.303 and the average of the diagram watts for $k = 0$ or e and c in phase is $w_1 = 53.33$.

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§ 43. When $k = s = 10$, making the lag equal one-quarter period, the diagram watts due to the exciting current can be calculated with comparative ease, as will be explained hereafter. When, however, the phase is between zero and s considerable detail work is necessary to perform the integrations, for the reason that the equations are only applicable between the limits plus and minus s. The positive and negative branches are symmetrical between these limits, but beyond, in either direction, the curve rapidly changes, developing infinite positive and negative branches.

§ 44. Either of the curves e or c, Fig. 9, may be generated

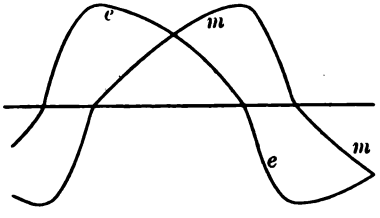

FIG. 8.—Series II, $u = 2$. (Distorted.)

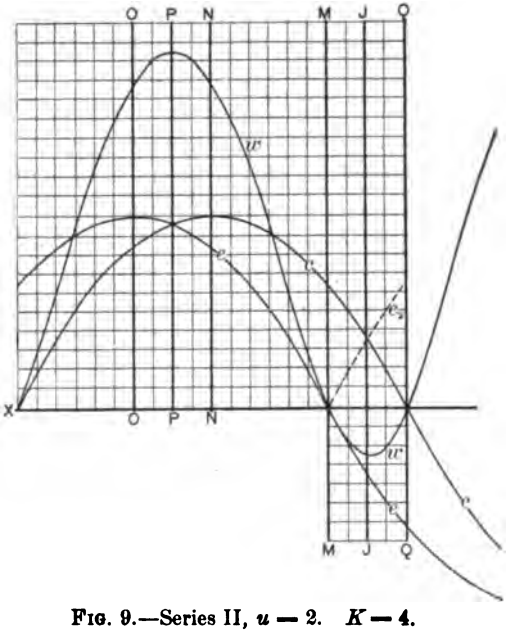

FIG. 9.—Series II, $u = 2$. $K = 4$.

from Eq. (11) by making the origin at the maximum value of the curve in each case. In order, however, to formulate coincident momentary values, it is necessary that both curves be referred to the same origin. This is accomplished by giving separate designations to the "generating abscissa" or those necessary to generate the two curves, and stating the values of the same in terms of a general abscissa, x.

§ 45. In addition to previous notation let:

x = generating abscissa of curve e of E. M. F.

x_c = generating abscissa of curve c of current.

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x = variable abscissa with zero at the origin assumed.

Also as already mentioned, §38, let:

k = "difference of phase."

§ 46. The equations of E. M. F. and current for $u = 2$, after substituting the generating abscissa as above in Eq. (11), take the following general form:

$$e = \frac{1}{s}\left(s^2 - x_e^2\right). \tag{16}$$

$$c = \frac{1}{s}\left(s^2 - x_c^2\right). \tag{17}$$

§ 47. Fig. 9 represents curves e and c of E. M. F. and current plotted in a scale of 10 units per quarter period, as per § 14, with current lagging 4 units or 36° per § 38, behind the E. M. F., shown by the fact that a time ordinate moved clockwise would reach the maximum ordinate of diagram current later than that of the maximum E. M. F. It is convenient to fix the origin at ordinate O, O, the maximum value of the curve of E. M. F., when the ordinates of curve e for a quarter period from O to M, Fig. 9, will be developed by simply making $x_e = x$ in Eq. (16) as shown in Eq. (18). Between the limits M and Q if $x_e = 2s - x$ in Eq. (16), as shown in Eq. (19), the ordinates of the resulting curve will be positive, as shown by curve e_2, Fig. 9, and give the same numerical values as if negative, with the advantage that in multiplying together the ordinates of e and c to obtain the diagram watts between these limits, the annoyances due to changes of sign when multiplying by a negative variable are overcome. The result should, however, be made minus, as evidently the diagram watts between the limits are minus. (See § 53).

§ 48. The ordinates of the curve c will be developed from the same origin, O, with due allowance for lag by making $x_c = k - x$ in Eq. (17) between limits O and N as shown in Eq. (20) and $x_c = x - k$ between limits N and Q, as shown in Eq. (21).

§ 49. The several equations then take the following form:

Between ordinates O and M

$$e = \frac{1}{s}\left(s^2 - x^2\right). \tag{18}$$

Between ordinates M and Q

$$e = \frac{1}{s}\left(s^2 - (2\,s - x)^2\right). \tag{19}$$

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Between ordinates O and N

$$e = \frac{1}{s}\left(s^2 - (k - x)^2\right). \tag{20}$$

Between ordinates N and Q

$$c = \frac{1}{s}\left(s^2 - (x - k)^2\right). \quad \text{(See § 56.)} \tag{21}$$

§ 50. Evidently for symmetrical curves the average ordinates of a watt curve for a single period or any number of periods, equals the average ordinate of a quarter period between the limits shown by the ordinates P and J, for which in this case $x = 2$ and 12 respectively.

§ 51. The values of the ordinates of the curves e and c between limits O and J as calculated from the above equations are given in Table 1. The right-hand branches of the curves shown in Fig. 9 are plotted from the ordinates as calculated for $u = 2$, $s = 10$ and $k = 4$, it being observed that the general value of x for Eqs. (19) and (21) is applicable between $x = 10$ and $x = 14$. The left-hand branches are constructed in the opposite direction from the same ordinates. There are also given in the last column of Table I. the products of the several corresponding ordinates $ec = w$ or the momentary diagram, watts developed, which are also plotted in Fig. 9 outlining a curve w. The ordinates of curve w are in a scale of 100, but are plotted on one-fifth of this scale for convenience of illustration.

§ 52.

TABLE I.

SHOWING VALUES OF GENERAL AND GENERATING ABCISSA AND CORRESPONDING ORDINATES OF CURVES e AND c IN FIG. 9. $u = 2$, $k = 4$.

Ordinates.	x and x_e	e	x_c	c	$ec = w$
O	0	10.0	−4	8.4	84.00
	1	9.9	−3	9.1	90.09
P	2	9.6	−2	9.6	92.16
	3	9.1	−1	9.9	90.09
	4	8.4	0	10.0	84.00
	5	7.5	1	9.9	74.25
	6	6.4	2	9.6	61.44
	7	5.1	3	9.1	46.41
	8	3.6	4	8.4	30.24
	9	1.9	5	7.5	14.25
M	10	0.0	6	6.4	0.00
	11	−1.9	7	5.1	−9.69
J	12	−3.6	8	3.6	−12.96

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§ 53. The work delivered to the apparatus by the generator is represented by the positive branch of the curve developed when e and c are of like sign, but this is ordinarily diminished by the smaller area of the negative branch of the curve when e and c are opposite in sign, this small amount of work representing the energy returned to the line by the apparatus.

§ 54. Evidently the area of the watt curves, and, therefore, their average height, can be obtained approximately from the calculated ordinates, and by increasing the number of such ordinates, or plotting a curve from those already stated and using the planimeter, still more accurate results can be obtained. It is gratifying to state, however, as indicated at the outset, that absolutely accurate results may be obtained by combining and integrating the equations. The operation, though not at all difficult, is a little tedious on account of the number of terms which are developed by expanding the binomials, multiplying together the equations of e and c and integrating the resulting terms. By this method, however, it is possible to obtain as accurate results with curves of various forms as can be obtained by the mean square and difference of phase method with sine curves.

§ 55. If we multiply together Eqs. (18) and (20), member by member, we obtain an equation of the momentary value of the diagram watts between limits to be explained.

$$e\,c = w = \frac{1}{s^2}\left(s^4 - s^2 k^2 + 2 s^2 k x - 2 s^2 x^2 + k^2 x^2 - 2 k x^3 + x^4\right). \tag{22}$$

Integrating we have:

$$G = \int y\,d\,x = \frac{x_1}{s_2}\left(s^4 - s^2 k^2 - s^2 k x - \frac{2\,s^2 x^2}{3} + \frac{k^2 x^2}{3} - \frac{k\,x^3}{2} + \frac{x^4}{5}\right). \tag{23}$$

§ 56. From the limits expressed in relation to the equations in § 49, Eqs. (22) and (23) above would appear to be applicable only between ordinates O and N, but since $(k - x)^2$ equals algebraically $(x - k)^2$ (although $k - x$ does not equal $x - k$), Eqs. (22) and (23) are really applicable between ordinates O and M, being limited by the value of e, Eq. (18) instead of the value of c. Eq. (22) may be employed to obtain either of the ordinates of the watt curve or the same may be obtained as in Table I, by first determining the corresponding ordinates e and c separately from the equations in § 49 and multiplying them together.

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§ 57. An integration of the watt curves between ordinates P and M is readily obtained from Eq. (23) between the limits, $x = 2$ and 10 respectively.

The value of the integrals will be found to be as follows:

	G	w_1
Between limits O and M, $x = 0$ and $x = 10$	626.67	62.67
Between limits O and P, $x = 0$ and $x = 2$. Deduct	178.84	89.42
Between limits P and M, $x = 2$ and $x = 10$	447.83	55.98

§ 58. The average of the diagram watts between the same limits equals the area divided by the base and is therefore:

$$w_1 = G \div x_1. \tag{24}$$

In the second column above, are given the values of w_1 for each integration.

§ 59. The next step is to develop, by multiplying together Eqs. (19) and (21), member by member, an equation corresponding to Eq. (22), the integral of which G, corresponding to Eq. (23), will be found to be as follows:

$$G = \int y\, d\, x = \frac{x_1}{s^2}\left(-8\, s^4 + s^2 x^2 - 3\, s^2 k\, x + 3\, s^2 k^2 + 2\, s^3 x\right.$$
$$\left. - s\, x^3 + \frac{8\, s\, k\, x^2}{3} - 2\, s\, k^2 x - \frac{s^2 x^2}{3} + \frac{k^2 x^2}{3} - \frac{k\, x^3}{2} + \frac{x^4}{5}\right). \tag{25}$$

which is applicable between ordinates M and Q.

§ 60. The values of the integral and average diagram watts between ordinates M and J, $x = 10$ and 12 respectively, on the basis that this integral is minus (see § 47 and § 53) will be found to be as follows:

G	w_1
—17.18	—8.59

§ 61. Adding the integral algebraically to that previously obtained, § 57, we have for the total integral for one-quarter period between ordinates P and J for $u = 2$, $k = 4$ ..... G = 430.65, w_1 = 43.065

§ 62. When $k = 10$ the current lags one-quarter phase behind the electromotive force, and but one integration is necessary viz.: the one first described where Eqs. (18) and (20 are combined, for the reason that the maximum current indicating its

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phase will have shifted to ordinate M or $k = 10$, and a complete integration for a whole quarter period is obtained by making $x = 10$ in Eq. (23). The result of the integration for e and c at one-quarter phase or 90° apart will be found to be $w_1 = \pm 36.67$.

§ 63. For $k = 0$ or e and c in phase $w_1 = 53.33$ derived from the $\sqrt{\text{mean}^2}$ value as given in § 42. The same result will be obtained by substituting $x = 10$, $k = 0$ in Eq. (23).

§ 64. Recapitulating, then, we find that for $k = 0$, or e and c in phase, § 63, $w_1 = 53.33$; for $k = 4$, § 61, $w_1 = 43.065$, and for e and c in quadrature $k = 10$, § 62, $w_1 = \pm 36.67$, the maximum possible being 100 as previously stated. The result for $k = 10$ represents watts for excitation. In general the apparatus is so proportioned that under these conditions the actual energy in the circuit is relatively much less in proportion than the diagram watts above stated, which are also to be corrected by the introduction of the coefficients for reducing diagram values to commercial units stated in § 18. These watts are of contrary sign every alternate quarter period.

§ 65. It should be borne in mind that the above illustrations apply only to one of the very many forms of curves which may be obtained by varying the value of u in the equations given, and for each of these curves the diagram watts may be found directly, for any desired difference of lag, without resorting to the suggestion recently made of reducing unusual curves to what are called "equivalent sine curves."

§ 66. Evidently, moreover, it is possible to use a different function for descending and ascending branches of the curves, thus producing unsymmetrical curves somewhat like those in Fig. 8 (see § 35) and yet perform the integrations, and this function may be developed by imposing upon the original function another function based on the actual conditions which produce a certain change, so that the curves finally resulting will include all of the conditions. It has been pointed out that the observed distortions may be illustrated by imposing upon the primary function a series of harmonics. To make such a method strictly rational it must be shown that each condition if formulated would produce the equation of such a harmonic. It is not probable that such is the case, but fortunately the present method gives facilities for considering the additional conditions, whatever the general shape of the curves that will represent them.

§ 67. It is to some extent unfortunate that the equations se-

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lected do not cause the curves to reverse direction periodically, and that the necessity of integrating between limits, and somewhat changing the forms of equations for different limits makes considerable detail work necessary to obtain the integrations, but on the other hand *it is very gratifying that integrations can be obtained at all* of quantities which so closely represent *actual* rather than assumed conditions. The paper deals with instantaneous watts derive from instantaneous values of electromotive force and current in the same way that similar deductions are made for direct current. The methods described of reducing final results from such values, though developed with considerable labor, involve only mathematics of the simplest order, which can readily be corrected if mistakes have been made, and cannot apparently give rise to any difference of opinions as to principles involved.

§ 68.

TABLE II.

DISTINGUISHING FEATURES OF THE DIFFERENT CURVES.

General Shape of Curves of E. M. F. and Current.					Diagram Watts in Scale of 100 e and c in phase.	$\sqrt{\text{mean}^2}$ in Scale of 10.	Relative Ratios Max. to Effective Voltage.
Triangle	Series I	$v = 1$	§ 25	Fig. 4	33.333	5.774	1.732
	" II	$u = 1$	§ 29				
Sine Curve	—	—	§ 32	" 1	50.000	7.071	1.414
Approximate Sine Curve.	Series II	$u = 1.7^{21}$	§ 32	—	50.000	7.071	1.414
Parabolic Curve	" II	$u = 2$	§ 31	Fig. 6	53.333	7.303	1.369
Approximate Rectangle	" II	$u = 6$	§ 34	" 7	79.120	8.895	1.124
Rectangle	" I	$v = 0$	§ 25	" 2	100.00	10.000	1.000
	" II	$u = \infty$	§ 33				

§ 69. In Table II. are presented the mean square values and ratios of maximum to effective voltage for a number of curves shown in the various figures, together with references to the partial exponents, the figures and the sections where the curves are described. It appears that the most desirable curve for lighting purposes would be a rectangle if the same were practicable. The approximate rectangle shown in Fig. 9 can probably be obtained with alternating current machines designed for the purpose. This curve would also give greater power than forms with less

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area, but it is not probable that the magnetism could be reversed with sufficient rapidity to secure proper reactions between the field and armature.

§ 70. It is thought that for power purposes the increment or decrement of magnetism which produces the E. M. F. should be constant, which condition would secure the maximum time possible for each momentary change in magnetism. The second differential coefficient of a parabolic curve is constant, so our first impressions were that the curve of E. M. F. should for power purposes be a parabola, but on further consideration it appears that, since it is the increment of change in magnetism which should be constant, the curve of E. M. F. should be a triangle and the curve of magnetization a parabola, as shown in § 29 and Fig. 4. The second differential coefficient of the equation of magnetization, which equals the first differential coefficient of the equation of E. M. F. represents the increment which should be constant. As the curve m passes through zero, its tangent, and consequently the E. M. F., is a maximum, the second differential coefficient of m changes sign and becomes a decrement, and as the time ordinate moves from left to right, the tangent to the curve m or the E. M. F. is decreased. Making this decrement equal to a constant, we have:

$$\frac{d\,m^2}{d^2 x} = \frac{d\,e}{d\,x} = -a. \tag{26}$$

Integrating we have the indefinite integral of the tangent to the curve of magnetization which equals the electromotive force, and finding the value of the constant of integration, C, from the condition that when $x = s$, $e = 0$, we have the corrected integral as follows:

$$\frac{d\,m}{d\,x} = e = C - a\,x = a\,(s - x). \tag{27}$$

Hence the rational form of the curve of E. M. F. for power purposes is a triangle, if it be accepted as desirable that the maximum time should be allowed for each magnetic change. Integrating again we have:

$$m = a\left(s\,x - \frac{x^2}{2}\right), \tag{28}$$

which is the equation of a parabola, as in Fig. 4, and is in the same form as Equation (12), with the exception of the arbitrary co-

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efficient assumed for this case. The astonishing feature of this part of the investigation is the remarkably small difference in the curve of magnetization required to cause the curve of E. M. F. to pass from a sine curve to a triangle. When e is a sine curve, m is also a sine curve, but when e is a triangle, m is a parabola, as in Fig. 4, and the difference between a sine curve and a parabola is only that between the dotted and drawn line of the curve e in Fig. 6, and variations of this small difference applied to a curve of magnetization will make all the difference between sine and pointed curves. The objection to a triangular curve of electromotive force is the additional strain that it imposes on the insulation on account of the high relative ratio of maximum to effective voltage. (See last column, Table II., § 68.) Ordinarily a pointed curve would be used, resembling a triangle with a rounded point, which it will be seen by comparing Figs. 4 and 6 would result from Equations (11) and (12, for values of u between 1 and 2. This question cannot be fully settled mathematically without considering modifications due to transformation, but the general principle is well worthy of careful consideration.

§ 71. The author is indebted to Prof. Harris J. Ryan for valuable suggestions during these investigations, though the professor has had no opportunity to examine the complete paper or to criticise the views of the writer in detail.

[For discussion see page 470.]

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A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27th, 1895. President Duncan in the Chair.

NOTES ON THE RECONSTRUCTION OF A SMALL CENTRAL STATION PLANT.

BY FRANKLIN L. POPE.

The financial condition of the smaller central station electric lighting plants throughout the country is at the present time by no means satisfactory, and in too many instances cannot even be truthfully said to be encouraging. A survey of the field shows that very few such plants located in towns having less than 10,000 inhabitants are earning more money than is necessary to meet their operating expenses and to provide for indispensable current repairs. In the state of Massachussetts, in which the operations of all electric lighting companies are by law made a matter of public record, it appears from the latest reports that the aggregate liabilities of the fifty-seven companies operating in that state, including stocks, bonds, and floating indebtedness, amounted on June 30, 1894, in round numbers to $14,000,000, nearly all of which stands charged to construction account. The net earnings for the preceding year were $1,000,000, or about 7.1 per cent. on the total investment: a sum obviously quite insufficient to provide for depreciation and at the same time pay a fair dividend on the capital which has gone into the business. But if half-a-dozen of the larger plants, in cities like Boston, Lowell, Worcester, Springfield, Lynn and Fall River were excluded from the list, the showing for the smaller plants would be even far worse than it now appears.

Many of these small plants were started at an earlier day than could have been justified by any reasonable estimate of the business then in sight, and now find themselves hampered by inconvenient buildings, and with unsuitable machinery bought at high prices,

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and encumbered with defective business methods which experience has shown to be wholly inconsistent with the dictates of good judgment.

With the owners of many of these plants, it has become a very serious question whether the easiest way out of the dilemma which confronts them, may not be to relegate the entire plant to the junk-shop and the scrap-pile, and commence over again with new buildings, modern machinery and improved methods of administration. When the necessary capital is readily forthcoming, there can be no doubt that this would often be the wisest course of procedure, but for obvious reasons, it is one which is not always, nor even usually practicable. The alternative is to remodel the existing plant, bringing it as nearly as may be into accordance with the best modern practice, and utilizing so far as possible, the old material; a course which at least has the merit of avoiding an undue expansion of the construction account, in most cases already sufficiently burdensome.

Having been called upon during the past year to advise the owners of a plant of the character above referred to, in reference to certain changes which had been suggested as desirable, and having afterwards been employed in a professional capacity to design the work and superintend its execution, I have thought that some account of what we undertook to do and how we did it, might not be without interest to the members of the INSTITUTE.

The Great Barrington (Mass.) Electric Light Company was organized and commenced business in 1888. The population of the district intended to be served was about 3,000, and most of the expected consumers were located within 2,000 feet of the point decided upon for the station. This was built of wood in the most inexpensive manner possible, and was placed alongside the railroad for convenience in receiving coal, although at the same time the danger from fire was materially increased. The original outfit was an Edison 3-wire, equipped with a pair of 250-light 110-volt dynamos, and the company commenced business with 281 lights on contract at $10 per year each; wiring free. The center of distribution was 1800 feet from the station, necessitating over a ton of copper in the feeders alone. Generally speaking, the plant was well laid out, and well built as things went in those days. The two dynamos were belted to a single 80 H. P. Armington and Sims engine. The original cost of the plant was about $16,000. The following year a Schuyler arc-

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plant for street-lighting was added, carrying 35 arcs, nominally of 1,500 C. P., which was run from the same engine and boiler. In 1890, the plant was considerably enlarged by the addition of a second arc machine, a Westinghouse 500-light alternator, and a second engine and boiler of the same capacity as the first. An 80 K. W. Westinghouse dynamo of more modern type was afterwards substituted for the original one.

Upon examining the plant last year, I found the Edison machines carrying on Saturday evenings a maximum load of some 450 lights, while three evenings in the week (with the stores closed) it fell to perhaps half that amount. The two Schuyler machines, with an aggregate capacity of 55 to 60 lights were carrying about 38 to 40, or an equivalent of that amount, while the Westinghouse machine was seldom as much as half-loaded, carrying a maximum of possibly 500 lights during three or four months of the summer season, and not much more than one-fourth that amount the remainder of the year. Necessarily, with so many dynamos of different types, and with such a variable, yet small average output, the consumption of coal was excessive as compared with the light delivered and paid for.

The street lines, according to the usual practice, were of No. 6 B. & S. weather-proof wire; the poles were of cedar, of good size and fitted with pine or spruce cross-arms, with common green glass insulators set upon wooden pins. In consequence of a silly prejudice, which had been fomented amongst the citizens by interested parties against permitting poles to be set in the streets, the wires, in a very great number of instances, had been attached, by cross-arms or brackets, to the trunks of the immense elm trees with which the streets of the town were shaded; a practice which occasioned an enormous loss of current every wet night as well as much irregularity in the performance of the lights. The effect on the trees was by no means salutary, while the appearance was as much worse than that of poles in the streets as could possibly be imagined.

The village of Great Barrington extends for the most part along a single broad thoroughfare for a distance of nearly three miles, and the street-lighting circuits are consequently very straggling. The 1500 C. P. lamps, which were suspended at intervals of 800 to 1,000 feet, were actually of very little service in illuminating the densely shaded streets.

After a careful consideration of the situation, keeping in

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view the greatest possible reduction of present and future operating expenses, it was determined the wisest course to pursue would be to consolidate the whole service so that it could be supplied by one dynamo, in place of five underloaded ones. In pursuance of this plan it was decided to adopt the two-phase alternating system, at a maximum pressure of 2100 volts in the primaries, and 105 volts in the secondaries, with a frequency sufficiently low to permit the advantageous use of induction motors if required. It was furthermore decided to abandon the steam plant, and to make arrangements to utilize some one of the excellent water-powers which were available within practicable distances. Under ordinary circumstances, I should have hesitated to recommend the substitution of water-power for steam as the sole source of power for the operation of an electric lighting plant. Water-power is an invaluable auxiliary, and when conveniently available for use in conjunction with steam, may often be made to save a very large coal-bill in the course of a year. On the other hand, the excessive fluctuations to which it is liable—which are scarcely realized by those but casually acquainted with the subject— render it in most cases a very uncertain reliance for a business which is compelled to go on, perforce, every night in the year, and which cannot suspend operations, as an ordinary manufactory does, if worst comes to worst, for a week or two at a time. Even a water-privilege which, during ten months of the year, furnishes twice as much power as is needed, and even more, may be expected to fall off, during one of the extraordinarily dry seasons which occur at intervals of from five to ten years, to one-third its usual amount. In such a case, an electric plant solely dependent upon water-power would find itself in a most undesirable predicament.

In the present instance, the choice of a water-privilege finally reduced itself to two sites, one in the town itself, within half a mile of the center of consumption, and the other at Glendale village, seven miles distant, both situated on the Housatonic river. The privilege first mentioned being already occupied by a woolen factory, only the surplus water was available, but this was known to be quite sufficient for the requirements of the electric company at least nine months in each year, leaving three months to be run by steam. It had the advantage of being close at hand, and was capable of being fitted up at a moderate cost. As to the Glendale privilege, it was necessary to be very

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sure that the lowest water of a dry summer would give all the power required to run the plant without the aid of steam. Having invariably found the value of a water-power to be greatly exaggerated, not only in popular estimation, but in the opinion of its owners, the matter was investigated with much care. From the official state map of Massachusetts, it was ascertained that the area of the drainage basin of the Housatonic above the Glendale dam was 269 square miles. J. T. Fanning, a leading authority, from an extended examination of the recorded observations on the rainfall and flow of the New England rivers, reaches the conclusion that a water-shed of the area mentioned, may be estimated to yield the quantities of water given below:—

CUBIC FEET OF WATER PER SECOND PER SQUARE MILE.[1]

Minimum (15 days of least summer flow)	0.25
Mean (120 days, usually July to October inclusive)	0.90
Maximum (flood volume)	80.00

It will be noticed that the flow in extreme dry weather is less than one-third of that which may ordinarily be depended upon through the remainder of the year.

The distribution of rainfall throughout the year should be studied. It is often materially modified by local geographical conditions. The diagram shows that the distribution on the head-waters of the Housatonic is quite different from the normal type of the northeastern region. The same may be true of other rivers.

While this investigation was going on, it was discovered that actual measurements of the volume of water in the Housatonic river had been made in 1878 by the engineers of the New York Department of Public Works, with reference to its utilization as a future source of water supply for that city. The minimum summer flow was found to be (as given in the engineer's report), 0.34 C. F. per second per square mile. It was also learned that measurements made on several different occasions at Birmingham, Conn, in very low stages of water, gave an average of 0.32 C. F. per second per square mile. It was therefore assumed that Mr. Fanning's estimates were at least on the safe side. The greater volume of water found by the actual measurements, is doubtless due to the fact that there are some 5 or 6 square miles of reservoirs, consisting of natural and artificial lakes, on the upper wa-

[1] Hydraulic and Water Supply Engineering. (3d ed.), p. 75; table 19. New York, 1882.

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ters of the Housatonic, which are drawn upon by the numerous mills on the river as an extra supply during the season of drought.

A minimum flow of 0.25 per second per square mile would give at Glendale, 4035 C. F. per minute. Multiplying this by the weight of a C. F. of water (63.3 lbs.) gives 255,415 foot-pounds, which, divided by 33,000 gives 7.74 gross horse-power per foot of fall, or a total of 99.6 H. P. for the 13 feet fall at Glendale. The average efficiency of a good turbine may safely be taken at 75 per cent. which would give 67.9 as the available H. P. during the whole 24 hours, in time of lowest water. In electric lighting however, the great bulk of work is done within a period of about 4 hours (in summer time), and hence it is possible, in case there is sufficient area of pondage above the dam, to increase this capacity

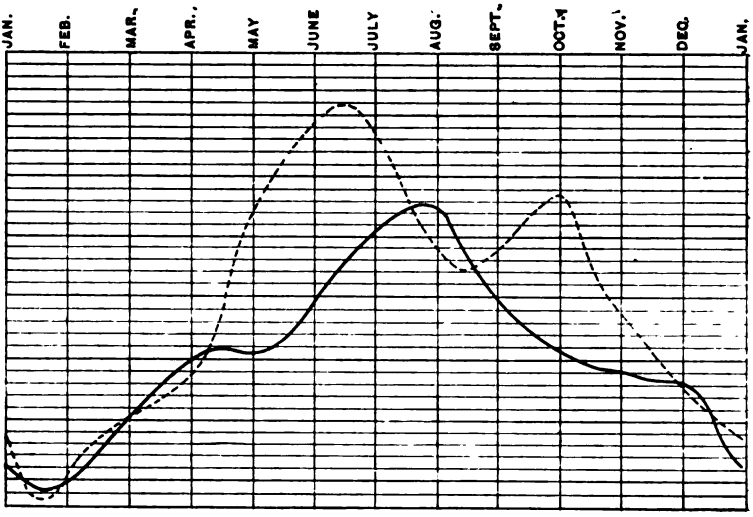

FIG. 1.—Curve of mean annual distribution of rainfall. Full line is reduced observations at Williamstown, Mass., 1816 to 1874. Dotted line is mean of all observations in the Hudson and Champlain valleys, and northern and western New York, aggregate 564 years. From Schott's Rainfall Tables, pp. 199, 251. Washington, 1881.

by storage at least four-fold, which would raise the limit of minimum available power during lighting hours, to 271.6 H.P.; an amount which was considered to be ample to meet all the probable requirements of the Great Barrington plant for many years to come.

While negotiations were still pending with the owners of the Glendale privilege, and also the one in the village already referred to, overtures were received from a manufacturing company owning a third exceptionally desirable privilege, on the

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same stream, at an intermediate point considerably nearer than Glendale. This company had only recently completed a new dam, head-gates, raceways, etc., at a very considerable expense, and was willing to lease the complete establishment, including a new McCormick turbine of 325 H.P. and a two-phase Stanley generator of corresponding capacity, at a monthly rental based upon the actual output as measured in kilowatt-hours at the dynamo terminals, provided that a certain minimum monthly consumption was guaranteed. With the same volume of water as at Glendale, the fall at this point was 20 feet, assuring at least 417 H. P. at lowest water, during lighting hours. All the hydraulic appparatus and appointments were of the best possible construction, and well-calculated to ensure absolute permanency of operation.

The minimum rental exacted was somewhat less than the amount of the coal-bill of the Great Barrington company for the preceding fiscal year, but while the immediate saving in operating expenses was not large, the acceptance of the proposition would place the company in a position to reduce its rates to consumers, for the reason that its output might be very largely increased without materially augmenting its operating expenses. A lease for a term of years was accordingly closed.

In laying out the plant it was determined to bring the main feeders directly to a distributing station in the village, to be used principally as a convenient headquarters for testing the circuits and controlling the street-lighting service. In laying out the transmission line, a surveyor was employed, and a preliminary line was run directly from the power-house to the distributing-station. The air-line distance was found to be 5.15 miles. With the assistance of the surveyor, the actual line was then staked out, going directly across country, and keeping as near as circumstances permitted to the transit line. About half the distance, the transit-line was found to so nearly coincide with existing highways, that the consent of the local authorities was obtained to set the poles along the highway location; the remainder of the route lay principally through uncultivated land of little value, so that a comparatively small expenditure was sufficient to secure a release from all claims for land damages. This enabled the line to be located with long stretches absolutely straight, avoiding all sharp angles; a very important consideration when heavy wires are used. The poles were of selected chestnut with natural butts.

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usually set five feet in the ground at maximum intervals of 125 feet. The poles were ordinarily 25 feet long and 8 inches thick at the small end. Shorter poles were sometimes used on elevations and longer ones in depressions, in order to equalize the strain as much as possible. The insulators used were of the large double-bell white porcelain type (German government standard), and were imported by us from Hagen. The insulator of the top wire is set upon a malleable-iron stem 14 inches long screwed into the top of the pole which is tapered to 5 inches diameter, and protected from splitting by driving on a wrought-iron ring. The tapered part of the pole, as well as the top, was given a coating of mineral paint mixed as thick as it could be spread with a brush. The insulator of the second wire is carried on a malleable-iron goose-neck, screwed into a $\frac{5}{8}$ inch hole bored in the side of the pole, in such position as to bring the wires about 16 inches apart. Another hole was bored on the opposite side of the pole, intended to take the goose-neck of the third wire at some future time, leaving the same interval between the second and third wires. The porcelain insulators are fixed to their iron supports by a packing of oakum placed between the screw-threads, which serves to prevent any danger of fracture by expansion or contraction. The line wire is laid in a groove formed in the top of the insulator, except upon the curves and angles, in which case it is tied at the side in a circumferential groove, as is usual in this country. The German method of tying is quite complex, and unnecessarily strong; in case of undue strain, if anything gives way it had best be the tie-wire. We therefore devised a simple tie which was easily and quickly applied, and which has so far served an admirable purpose. We were obliged to string the wires during very cold weather; sometimes as cold as 8 or 10 degrees below zero, and hence it was necessary to strain them very tight. A block and fall and a well-trained horse were used in pulling up, usually six or seven spans of one wire at a time. The hook of the block was was always attached to the copper wire, whether bare or insulated, with a chain-knot made of $\frac{3}{4}$ inch rope. The feeder-wires were of No. 3 B. & S. soft copper, covered with weather-proof "insulation" along the highway (as a concession to enlightened public opinion), but elsewhere bare. The lengths of wire were joined with McIntire twisted couplings; the unusual strain we had to put upon them occasionally pulled one apart, and this led us, out of abundant caution, to solder them, although this was done for

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mechanical rather than for electrical reasons. Only two feeder wires have as yet been strung, providing for a single-phase current from one side of the two-phase generator, but it is the intention to run a third feeder at an early day, which will enable two-phase induction motors to be connected to the same distributing system.

A pair of telephone wires of No. 12 steel were strung below the feeder-wires, and these were supported upon small German porcelain insulators on iron goose-necks on opposite sides of the poles. These wires were transposed at intervals of about a mile, in order to eliminate the inductive effects of the alternating current in the feeders. The feeder-lines were carried under the railroad at an undergrade crossing by placing the insulators upon iron brackets leaded into the stone abutments. The plan of construction above described makes a strong, handsome and durable line, while the insulation of the circuit even in the worst of weather, is simply faultless.[1]

The system has been planned to deliver the current at the distributing station at a uniform pressure of 2,100 volts. Two distributing centers were fixed upon in the old Edison 3-wire network, and at each of these points a pair of large transformers, having a ratio of 20 : 1, were fixed upon a pole, with their respective primaries in series between a pair of branch feeders from the distributing system, and their secondaries were coupled in series in like manner with the neutral wire between them. None of the consumers on the old Edison system knew when the change had been made to the new service from anything they were able to notice in the behavior of the lights.

1. I regret that I am unable to present any actual measurements of the insulation of the line of the Great Barrington company, no opportunity having occurred since the work was completed, of making tests under atmospheric conditions of minimum insulation. Several years ago, however, while engaged in telegraphic service, I made a series of nearly 100 separate tests in rainy and foggy weather, extending over a period of five years, of a set of 10 porcelain insulators of the same make and pattern in every particular as those now on the Great Barrington line, erected on a house-top in the city and therefore much exposed to smoke and dirt. These measurements gave a mean resistance of 28.3 megohms, and a minimum resistance of 19 megohms per insulator. On a metallic circuit therefore, the minimum insulation resistance at each pole would be 38 megohms. On the Great Barrington line of 28,260 feet there are 250 poles and other supports, and hence we may assume that the minimum resistance of the insulation of the circuit as a whole would be 152,000 ohms. The current loss by leakage is found by dividing the mean voltage by the insulation resistance ; $\frac{2,200}{152,000} = 0.014$ ampere ; an amount too small for serious consideration. The conductivity resistance of the feeder circuit measures 9.07 ohms at 0° Centigrade (32° Fahr.)

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The next thing done was to reconstruct the street-lighting system. In place of the 36 arcs of 1500 nominal C. P. formerly in use we substituted 126 incandescent lamps of 50 volts and 32 C. P., placed in Iona fixtures projecting horizontally from the poles 14 feet above the ground. The lights, as a rule, were fixed upon every alternate pole, but in the business center, the street being broad, they were placed on each side at intervals of about 250 feet, and staggered, so as not to come opposite each other. A Shallenberger shunt cut-out was applied to each lamp. The usual number of lamps in each circuit was 42, although we have since placed, in some cases, as many as 47 in one series without reducing the brilliancy of illumination sufficiently to be noticeable by any one but an expert. One end of each street-lighting circuit is joined to a special feeder leading to the sub-station, where it is connected with the main feeder through a knife-switch. The other end of each lamp-circuit is connected to any conveniently located branch feeder of the regular commercial lighting service. Each lamp-circuit has, or will have, a fuse-block and cut-out enclosed in a weather-proof box at each end, where it joins the opposite feeders. These 32 C. P. lamps, when run at full candle-power, furnish a most satisfactory illumination and give the streets a very attractive appearance. So far as possible, each lamp was located with the aid of a transit and level, so as to get them in absolutely straight lines both vertically and horizontally, a precaution which adds materially to the decorative effect. It is admitted by all that the streets of the town are much more satisfactorily lighted by the incandescents than they formerly were by arc lamps, while the actual cost to the company is considerably less. The new lamps were cut in, one at a time, on the old arc wires, jumpers being temporarily placed across the terminals until everything was in readiness to discontinue the use of arc machines.

One of the most marked advantages of the series street-lighting system, especially when shunt cut-outs are used, is its great flexibility and convenience. For example, instead of placing from 40 to 45 50-volt lamps in one series, we may use 20 to 23 100-volt lamps, or if a smaller number be required, less than is necessary to make up a circuit, the deficit may be supplied by adding extra shunt-boxes in series at any convenient point in the circuit, until the pressure has been reduced to the required point. From time to time, as new lights are added, these spare shunt-boxes are one

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after another brought into use in connection with them. Sometimes, also, we temporarily install extra street-lights by connecting them in parallel to the secondary mains of the regular commercial service, ultimately transferring them to new series circuits.

It has been found to be desirable to use a lamp of rather low efficiency for the street-lighting service, as there is always danger of leakage and short-circuits from wet boughs of trees and other objects getting into contact with the wires, and thus diverting an abnormal current through some portion of a lamp circuit. In such case, a lamp of high efficiency is pretty certain to be burned out, or at least to have its career of usefulness materially abridged. In this plant, the average consumption of energy in the street-lights, including lamps, lines, shunts, and leakage is found to be about 140 watts per lamp of 32 C. P.

Perhaps the most ticklish part of the whole undertaking was the changing over of the Westinghouse system, which was a 1050-volt primary and a 52-volt secondary, running at 16,500 alternations. In accordance with the new plan, it was of course necessary to double the pressure both in the primary and secondary circuits, and to substitute 104-volt for 52-volt lamps throughout. A preliminary test of one of the transformers demonstrated, that which perhaps might have been foreseen from theoretical considerations, viz.: that a dangerous quantity of heat was developed within a few hours when it was used to convert from 2,000 volts down to 100. In order to utilize, so far as possible, the old transformers, and at the same time avoid the above difficulty, various expedients were resorted to. Wherever a group of consumers was located in one neighborhood, a pair of large transformers was installed, with secondary mains extending from 500 to 600 feet in various directions; these transformers being of course placed in series with each other. Scattering consumers as far as practicable were united in pairs or small groups, and supplied by a pair of small transformers coupled in the same way. The Westinghouse meters, having been originally constructed for a frequency of 16,500 alternations, ran slow when the frequency was reduced to 8,000. The necessary coefficient for correction of the readings was easily ascertained by experiment, and as fast as possible the meters were fitted with new disks, supplied by the Westinghouse company at a trifling expense, adapted to the lesser frequency.

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Of course it will be understood that the reason for resorting to these various shifts and expedients, was merely that we might utililize the old apparatus as far as it could possibly be done, and also that we might carry on the work of reconstruction, for the most part, with the ordinary working force of the establishment.

The horizontal double turbine which is used to drive the two-phase generator has done such good work that it deserves a few words of commendation. The selection of the best among the many available types of turbines for electric work is a matter which merits far more consideration from a scientific standpoint than it generally receives. Water-wheels, like dynamos and motors, are sometimes sold on commission by agents, and it not infrequently happens that the salesman who makes the largest "claims," especially if he sells his goods the cheapest, carries away the contract. It needs to be said, however, that there is a far greater difference than is often suspected, in the work that different types of wheels will do with a given, and especially a limited amount of water. There are, furthermore, a great many types of wheels in the market, which although as efficient as could be asked for with a full head of water, are very far from being so when the volume of water is reduced, even by a comparatively small percentage. It is but just to say that it is seldom that a turbine makes so favorable a showing, not only in this but in other respects, as the one provided by the company from which we lease our power. The following figures are selected from a much larger number obtained by actual measurement of its performance, in the testing-flume of the Holyoke Water-power Company.

Head acting on Wheel feet.	Revolutions per minute.	Quantity of water passing through Wheel (cu. ft. per sec.)	Horse-Power.	Per cent. of Efficiency.
16.56	135.25	83.56	124.22	79.25
16.60	156.25	81.75	124.50	80.99
16.80	155.00	70.79	109.37	81.18
17.02	154.50	63.42	95.86	78.39
17.26	156.75	52.19	73.42	71.95
17.44	152.25	42.55	53.71	63.90

These results are worthy of particular note, for the reason that they show a very high percentage of efficiency maintained through a wide range of variation in the quantity of water passing through the wheel; a most valuable characteristic for elec-

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tric work. When the quantity of water used was diminished from 81.75 to 42.55 cubic feet per second, the percentage of efficiency fell only from 80.99 to 63.9, and what is even more remarkable, it was found that the efficiency remained well above 80 per cent. over a range of variation of discharge from 83.22 to 70 cubic feet per second, or 15.9 per cent. More than one type of turbine which enjoys a high reputation and extensive sale among power-users, will not reach 65 or even 60 per cent. efficiency at "three-quarters gate," while the 33″ wheel above referred to has been found to give by actual test no less than 78 per cent. under similar conditions.

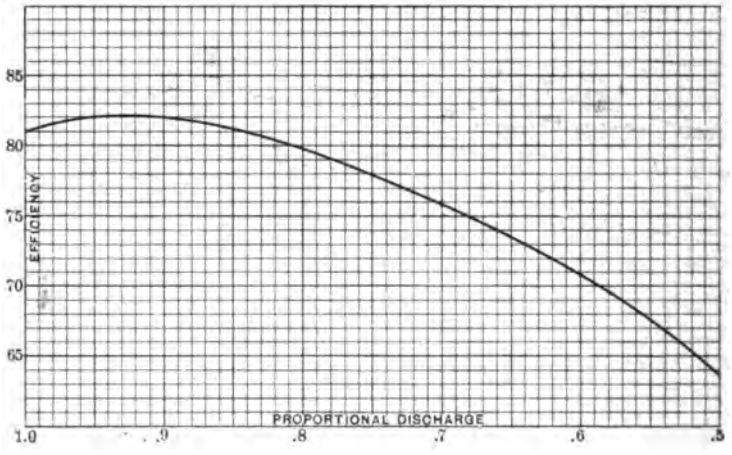

FIG. 2.—Efficiency Test of Jolly-McCormick Turbine.

The turbine carries upon its shaft a driving-pulley 100 inches in diameter, weighing 11,000 lbs. which serves as a balance-wheel. It is also provided with a Replogle electric governor operated by three cells of gravity battery, which has never failed to do its work quickly and certainly, even under trying conditions.

In carrying out this work, some things have been learned by experience which may be of use to others called upon to advise or to undertake the construction of similar works, and I will therefore venture to summarize some of my conclusions as follows:

1. In considering the advisability of operating an electric plant

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by water-power, do not on any account neglect to ascertain from authentic sources of information, just how much water can be depended upon during the low stage in an extra dry year, *for this is the measure of its value for electric work* except when used as an auxiliary to steam. The ordinary estimates of the commercial value of a water-power are only too apt to prove preposterous exaggerations.

2. If rights-of-way or releases of damages can be obtained without too much trouble and expense, it is better to build the feeder line as directly across country as may be, than to follow a highway. The saving in cost of construction will usually be more than enough to pay for the right-of-way, and on such a route there need be no interference from trees, while many inconvenient angles and much trouble in guying and bracing are avoided. Shorter and stouter poles may also be used; in itself a very important consideration.

3. In electric line construction it is preferable to dispense with cross-arms unless there are more than six wires. The best arrangement is to place one wire on a top-pin and the others alternately on the front and back of the pole, at a vertical distance apart of 12 inches. This construction not only costs less than properly braced cross-arms, but is much less conspicuous and therefore much less objectionable in a public street, is less interfered with by trees, and is far more durable. Much trouble is caused by the decay of cross-arms after they have been exposed a few years to the weather; they split at the ends so that the pins come out, and not infrequently break in two in the middle, thus fouling the wires.

4. In medium-sized towns and cities, especially in shaded streets, the incandescent lamp may be made to give a far better distribution of light for the same money than is possible with the "half-arc" so extensively used, and is much less troublesome to maintain in good working order. My own experience leads me to think that the lamps ought not to be of less than 24 or more than 32 candle-power. Use lamps of low rather than high efficiency, but run them at full candle-power, or even a trifle above. Good street-lights, well arranged, and renewed sufficiently often, are the best possible advertisement for any electric company.

5. Use large transformers as far as practicable, placing the consumers within 500 or 600 feet radius upon secondary mains. We

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have used both two-wire and three-wire mains. The latter plan is certainly to be recommended when the distance approximates or exceeds 500 feet, but for short distances, as for example when distributing within a single block at a pressure of 100 volts or more, it is a question whether the gain in cost of copper over the two-wire plan is of sufficient importance to offset the additional complexity.

6. It was found that raising the voltage in the residence district from 1,000 : 50 to 2,000 : 100 greatly improved the uniformity of distribution by lessening the potential drop without entailing any corresponding disadvantages. It would seem to be preferable, on every account, to use the higher pressure.

7. One of the most important minor points in the management of a plant is apt to be too much neglected; the maintenance of the insulation of the wires by promptly replacing all cracked and broken insulators, and by keeping the wires absolutely free from contact with uninsulated objects. The covered wires which lead into the hoods of the street-lamps need to be carefully looked after.

8. Number all the poles with yellow paint applied with a stencil on a black ground; and keep a record book of the position of each one and its distance by the line from the test-station.

9. In selecting a turbine-wheel, consult competent authorities as to the available fall and minimum quantity of water, and when making the purchase do not expect to get a thousand-dollar wheel for a hundred dollars. Pay a fair price and insist, not only that the wheel shall be well made in every way, but that it shall be tested by an expert before acceptance. If it does not give an average efficiency of 76 per cent. between half-gate and full-gate, it is not advisable to accept it, inasmuch as you can easily do better, as our own experience proves.

10. I think our experience shows that it is possible to largely increase the net earnings of an old plant without necessarily renewing it throughout, but plenty of time should be taken for consideration as well as for execution, in order to secure satisfactory results with a moderate expenditure.

Discussion.

Dr. Emery :—Although we are waiting for something of general interest I do not think that this paper should be passed without a word or two. The subject of the reconstruction of non-paying electric plants along modern lines is becoming of in-

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creasing importance, and I have studied this paper with a great deal of interest. It is an example of a typical engineering paper. The various steps taken are enumerated, and the reasons for each step, and the author has gone somewhat outside of what may be strictly called electrical engineering; taken up problems from the standpoint of a civil engineer and given reasons based on the same considerations as those used in that branch of engineering. The paper will repay careful perusal by all who may have similar problems to undertake. The basis assumed, viz., that the maximum power which can be relied upon depends upon the minimum rainfall and proportional stream flow, is the correct one and is only varied where there are large reservoirs so regulated as to store water during freshets, and supply it in times of drought. There is only one drawback in the discussion of the water question which has not been mentioned. The ice frequently causes trouble, in Northern climates particularly, and at a season of the year when light is most desirable, so that the length and location of the head races, together with all available data as to ice gorges in the river, should be well considered before making a change of this particular kind.

[An illustrated description of the Niagara Falls plant was then given by Dr. Coleman Sellers and Mr. Lewis B. Stillwell.]

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Twelfth Annual Meeting.—Morning Session.

Niagara Falls, N. Y., June 28, 1895.

President Duncan called the meeting to order at 10.30 A. M.

The President:—As it was impossible yesterday to discuss Dr. Emery's paper on "Alternating Current Curves," it has been thought best to open the proceedings this morning with a discussion of that paper. I will ask Dr. Pupin to open the discussion. [See paper page 433.]

Dr. M. I. Pupin:—I intended to indulge in a brief comment on Dr. Emery's paper, but a short conversation with Mr. Steinmetz convinced me that he had gone into the subject of the paper so thoroughly and exhaustively that it will be best for me to leave the whole discussion to him. There is one point only that I will mention, and that is, that I really do not see why Dr. Emery calls this a paper on alternating current curves. As I understand the meaning of the term, alternating current curves are those that are obtained experimentally from alternating current machines. The only reason that I can see for Dr. Emery's calling these curves alternating current curves, is because they resemble certain experimental alternating current curves, and evidently the object of the paper is to show how we can represent a certain class of alternating current curves approximately by means of an algebraical equation. I must object to what appears to me to be a favorite method of mechanical engineers. They are accustomed to represent some of their important physical facts by means of empirical formula, and they are satisfied if their formula represent facts with an approximate degree of accuracy. In electrical engineering we have no necessity for empirical formula, at any rate not in this case, and it is not a step forward, but a step backward to substitute an empirical formula in place of an exact formula. After all, in theoretical and in practical electrical engineering we are not troubled very much by difficulties concerning the integration of functions which in any particular case represent the waves of current, etc. A difficulty that we meet is to construct an instrument that will perform our integrations, as for instance, the wattmeter. I do not see that Dr. Emery's paper has suggested any way of overcoming these difficulties. These difficulties exist now just as much as they existed before Dr. Emery wrote his paper, as for instance the difficulty of making a wattmeter give correct readings when both the alternating E. M. F. and the current, or any one of the two do not follow the simple sine law. But as we all know, this difficulty appears only at small loads. When the secondary load increases, then in most cases both the E. M. F. curve and the current curve conform very nearly to the simple sine law, and our wattmeter gives correct readings.

Mr. Steinmetz:—When first reading, and now hearing this paper on alternating current waves, I must confess I have not been

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impressed very favorably with the desirability of introducing an empirical formula to represent these waves. It is true, in mechanical engineering, and sometimes even in electrical engineering, we are obliged to use empirical formula occasionally, wherever a rational equation is not available or is not known. However, I cannot see any reason for attempting to represent by empirical formula, phenomena of which a rational equation is in evidence, as is the case with alternating current and alternating E. M. F. waves. For these a rational formula exists: Fourier's series. All these alternating waves, no matter what shape and form they have, have one common feature, that is, they are

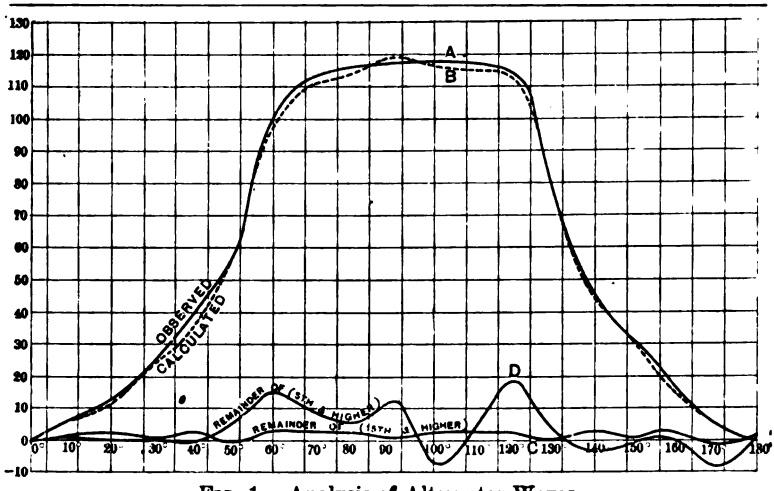

FIG. 1.—Analysis of Alternator Waves

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_1 \sin i\,\varphi + y_1 \cos i\,\varphi) \quad [i = 2\,n - 1]$$

Monocyclic Machine A.M. 12—150—600. Main coil. At no load.

Sine components of wave	Cos. components of wave
$f'(\varphi) = \sum_{i=0}^{i=\infty} x_1 \sin i\,y$	$f''(\varphi) = \sum_{i=0}^{i=\infty} y_1 \cos ix$
$x_1 = 104$	$y_1 = -3.86$
$x_3 = -24.5$	$y_3 = 4.33$
$x_5 = -4.8$	$y_5 = .72$
$x_7 = 6.9$	$y_7 = -1.48$
$x_9 = -2.62$	$y_9 = 1.$
$x_{11} = -1.78$	$y_{11} = .63$
$x_{13} = 2.75$	$y_{13} = -1.21$

$$e = f(\varphi) = 104.2 \{ \sin(\varphi - 1^\circ\,10') - .242 \sin(3\,\varphi - 9^\circ\,55') - .046 \sin(5\,\varphi - 8^\circ\,35') + .068 \sin(7\,\varphi - 11^\circ\,42') - .027 \sin(9\,\varphi - 20^\circ\,50') - .018 \sin(11\,\varphi - 19^\circ\,50') + .29 \sin(13\,\varphi - 23^\circ\,50') \}$$

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univalent functions of time, or in other words, for every value of time, one value only of the function exists. This is self-evident. But as a mathematical conclusion from this feature we derive that all these waves can be expressed by an infinite series of sine functions, and a rapidly convergent series, which with alternating machine currents consists of odd terms only, so that all these variously shaped curves can be expressed by very few terms of sine functions.

This equation is in evidence, and is very convenient, since in the integration of products of such series, all the terms vanish except the products of harmonics of equal order, so that the quadrature integral of such a series is nothing but the series of quadrature integrals of the individual terms.

Under these circumstances I do not see any reason for the introduction of the empirical formula in place of the rational equation.

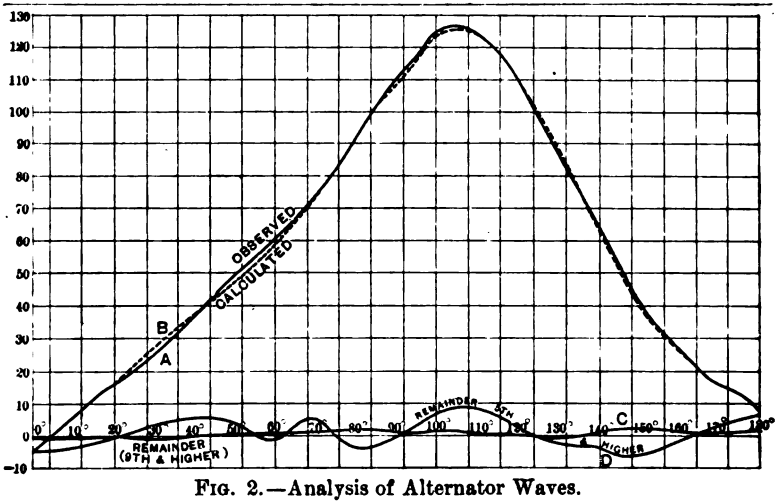

FIG. 2.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_1 \sin i\,\varphi + y_1 \cos i\,\varphi) \quad [i = 2\,n - 1]$$

Monocyclic Machine A.M. 12—150—600. 1,0 0 volts. Main coil. At 100 amp. load.

Sine components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} x_1 \sin i\,y$	Cos. components of wave $f''(\varphi) = \sum_{i=0}^{i=\infty} y_1 \cos i\,x$
$x_1 = 8$	$y_1 = -15.4$
$x_3 = -12.4$	$y_3 = 15.6$
$x_5 = -1.08$	$y_5 = -5.93$
$x_7 = -.232$	$y_7 = .70$

$$e = f(\varphi) = 99.21 \{ \sin(\varphi - 8^\circ\,58') - .20 \sin(3\,\varphi - 51^\circ\,40') - .061 \sin(5\,\varphi + 79^\circ\,41') - .0074 \sin(7\,\varphi - 71^\circ\,50')$$

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However, even if we attempt to represent these curves by an empirical formula, I believe the exponential function proposed here is very unsuitable, for the reason that all the more common alternating waves contain numerous inflection points and extreme points. The exponential function, however, does not contain any inflection point or extreme point. Therefore in analyzing an alternating wave, wherever we meet any inflection point, or extreme point, we have to drop the previous exponential function and introduce a new function. This means that every half wave has frequently to be represented by as many as 8 or 12 or even more different empirical functions. This introduces a complication in the handling of these functions with which the complexity of Fourier's series is nothing, even if we go as high as the 19th harmonic or so.

When looking over the curves given as instances in the paper, I must confess that outside of the sine wave I have not found any figure resembling a real alternating wave, that is, such a wave as is given by an alternating current dynamo where electric conductors revolve through magnetic fields, and when glancing over the numerous E. M. F. waves which came to my observation, and of which I have a collection here, I must confess that it appears utterly impossible to represent them by exponential functions with any degree of simplicity.

I have here, for instance, in Figs. 1 and 2, a very simple wave, the E. M. F. wave of the main coil of a standard 150 K. W. monocyclic generator at no load and at load. This is a very simple wave, that is, contains a quintuple and a septuple harmonic of opposite sign. Looking back to the equation derived from a test of such a machine you see a quintuple harmonic of 23 per cent. and a septuple harmonic of 13.4 per cent., of opposite sign with that of the quintuple, in complete agreement with theory.

Thus these higher harmonics and Fourier's theory are not merely mathematical fictions, but rational representations of phenomena taking place in the machines.

DR. EMERY:—I feel very much gratified with the kindly way this paper has been received. I cannot, however, accept the indictment that I have presented empirical formula except in the same sense that that of the sine curve is an empirical formula. All are representative curves. My formula take in what is practically a sine curve as a special case, together with a large number of other curves. The formula are therefore in a sense more general than the sine function, though due credit has been given to the latter for the facility with which general investigations can be conducted when conditions not always practical are assumed. The curves given by electric generators are rarely sine curves. One may show an approximate sine curve which can without serious error be represented by and treated as a sine curve, but my system includes approximate sine curves and a large number of other curves which represent actual curves as

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accurately as the sine curve does those of a particular form. In the investigation of principles we must put in place of the thing we have not, something which represents it approximately, whether it be by the development of a sine function or any other. I have made an attempt to develop an equation which, with different exponents, will represent a number of curves of practically typical forms, including the sine form, instead of being confined to the latter, and I have thought the investigation of sufficient importance to bring it here for the study of others. I have progressed further than I have attempted to present, but, regular business pressing, I became very much fatigued, and thought it better to put in shape what I had already developed, in the hope that it would interest and perhaps be extended by others. I believe that the method of investigation by means of actual momentary values will meet with increasing favor, and as the momentary values of E. M. F. and current must be multiplied together to give the momentary watts, I have endeavored for this purpose to produce simple equations that would apply closely to actual curves of different shapes. It is true that by assuming the sine function, direct values of the watts may be easily obtained for a given phase, and even approximate watts obtained for other curves, by considering equivalent sine curves and equivalent differences of phase, but after all the whole system is an artificial one. From the impressed E. M. F. two geometrically equivalent E. M. F.'s are assumed which is a well-known device to obtain certain solutions. For sine curves, mere power relations are accurately obtained in this way. The intermediate phenomena which actually produce the results are, however, smothered and concealed. The method of momentary values works out exactly as for direct current, and every operation can be traced. The equations given are only tools furnished to assist in the prosecution of a higher order of investigation. If in a given case the experimental curve of a given generator under particular conditions can be represented by one equation, by equating also the condition which causes a change, such condition may be imposed upon the first equation, thereby modifying the form of curve so that it corresponds practically with the experimental curve under the changed condition. The resulting momentary values have as before the same relations as in direct current work. This field of investigation will be found fascinating and instructive, and my first object has been accomplished by the introduction of the subject to others.

MR. STEINMETZ:—I cannot quite agree with Dr. Emery that alternating machines do not give sine waves. Amongst other waves I have here in Figs. 7 and 8 the E. M. F. wave of a 300-K. W. three-phase generator, at no load and at load, which wave is practically a perfect sine, that is, the deviation of this wave from a true sine is within 2 per cent. or within the errors of observation.[1]

1. This machine is the same of which the field characteristic is given as Fig. 14 in my paper on "Some Features of Alternating Current Systems."

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However, even where a wave is not a sine wave, but contains higher harmonics, it must not be thought that the separation of the total wave into the fundamental and the higher harmonics as done by Fourier's theory is merely a mathematical fiction. It is not fictitious but rational, and these higher harmonics have a real existence and find their origin in the machine in a way which can be accounted for by the shape of the magnetic and electrical circuit of the machine, and even predetermined by calculation.

Some months ago a friend of mine, Mr. E. J. Berg, made a mathematical investigation on the origin of these higher harmonics, which he intended to bring as a paper before the INSTITUTE for this meeting, but did not quite finish in time. He arrived at some very interesting results on the origin of these higher harmonics.

If the reluctance of the magnetic field of the alternator is uniform in all directions, the E. M. F. wave is very closely a sine wave. However, as soon as variations of magnetic reluctance take place, as by the passage of armature slots across the field poles, higher harmonics are introduced. Thus, if the armature contains k slots per pole, the magnetic reluctance will rise and fall k times per half wave, that is, will fluctuate with the frequency $2\,k\,N$, where N is the frequency of the alternator, and thus if we denote by M the average magnetic flux issuing from the field pole, then the instantaneous flux will be denoted by

$$m_0 = M\,(1 + \varepsilon \cos (2\,k\,\varphi - \tilde{\omega}))$$

where $\varepsilon\,M$ is the amplitude of the magnetic variation, $\tilde{\omega}$ its phase angle, and the instantaneous magnetic flux interlinked with the armature conductors will be denoted by

$$m = M \sin \varphi\,(1 + \varepsilon \cos (2\,k\,\varphi - \tilde{\omega})).$$

Differentiating this, we get as the equation of E. M. F.:

$$e = A \left\{ \cos \varphi + \frac{2\,k + 1}{2}\,\varepsilon \cos [(2\,k + 1)\,\varphi - \tilde{\omega}] \right.$$
$$\left. - \frac{2\,k - 1}{2}\,\varepsilon \cos [(2\,k - 1)\,\varphi - \tilde{\omega}] \right\}.$$

As you see, the E. M. F. wave contains two sine waves due to the variation of magnetic reluctance.

If $k = 1$, as in a uni-tooth alternator like the monocyclic machine mentioned above, this equation gives:

$$e = a \sin (\varphi - \tilde{\omega}_1) + b \sin (3\,\varphi - \tilde{\omega}_3).$$

That means, you get a fundamental and a triple harmonic, but no higher harmonics. This agrees with the test.

If $k = 3$, as in a uni-tooth three-phaser, the E. M. F. equation becomes:

$$e = a \sin (\varphi - \tilde{\omega}_1) - b \sin (5\,\varphi - \tilde{\omega}_5) + c\,(7\,\varphi - \tilde{\omega}_7).$$

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It only contains a fundamental and a triple harmonic. The latter being 24 per cent. of the fundamental at no load and 20 per cent. at load. All the higher harmonics are very small and practically negligible. The exact equation of the wave is:

No load: $\sin \varphi_1 - .242 \sin (3\varphi - 6.3) - .046 \sin (5\varphi - 2.6) + .068 \sin (7\varphi - 3.3) - .027 \sin (9\varphi - 10.0) - .018 \sin (11\varphi - 6.6) + .029 \sin (13\varphi - 8.2)$,

100 amperes load: $\sin \varphi - .20 \sin (3\varphi - 24.6) - .061 \sin (5\varphi + 124.7) - .007 \sin (7\varphi - 8.8)$;

but it can with sufficient exactness be expressed by the first two terms only:

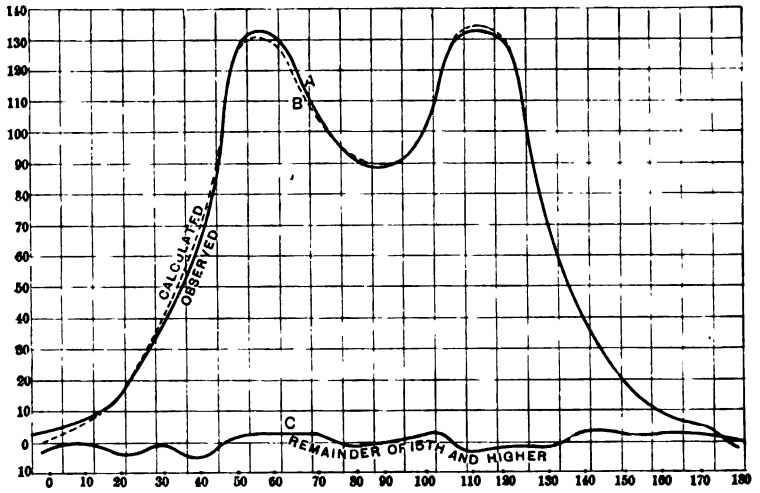

FIG. 3.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_1 \sin i\varphi + y_1 \cos i\varphi) \quad [i = 2n - 1]$$

Uni-tooth Threephase Machine A.T. — 12 — 150 — 600

Y. E. M. F. at no load.

Sine components of wave $f(\varphi) = \sum_{i=0}^{i=\infty} x_1 \sin i x$		Cos. components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} y_1 \cos i x$	
$x_1 =$	109.5	$y_1 =$	10.5
$x_3 =$	— 12.8	$y_3 =$	— 3.25
$x_5 =$	— 22.8	$y_5 =$	— 10.6
$x_7 =$	— 12.4	$y_7 =$	7.87
$x_9 =$	— 0.55	$y_9 =$	.245
$x_{11} =$	— 2.95	$y_{11} =$	— 4.2
$x_{13} =$	.595	$y_{13} =$	3.38

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No load: $\sin \varphi - .242 \sin (3 \varphi - 6.3)$,

100 amperes load: $\sin \varphi - .20 \sin (3 \varphi - 24.6)$.

Representing this curve by exponential functions, we would require for every half wave four different functions, and you can imagine how difficult it would become by using four different functions for various lengths of the same half wave, how difficult to handle these formula, infinitely more difficult than to use two sine functions.

The matter becomes still worse when you take, for instance, the wave of the standard 150 K. W. three-phase generator of which Figs. 3 and 4 give the E. M. F. wave per circuit, that is between collector ring and common connection, Figs. 5 and 6 the E. M. F. wave between lines. Figs. 3 and 5 correspond to no load, Figs. 4 and 6 to 25 amperes load of the machine, at 2,000 volts. These

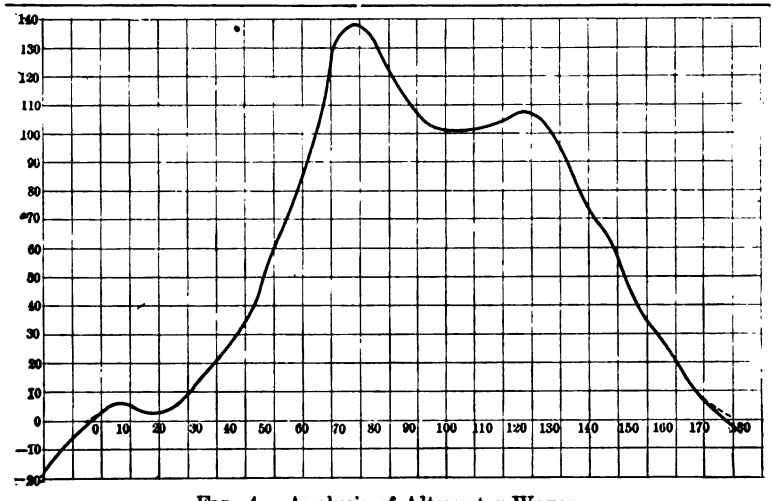

FIG. 4.—Analysis of Alternator Waves.

$$e = f(\varphi) = \sum_{i=0}^{i=\infty} (x_1 \sin i \varphi + y_1 \cos i \varphi) \quad [i = 2n - 1]$$

Unitooth Threephase Machine A.T. — 12 — 150 —600.
2,000 volts. Y. E. M. F. at 25 amp. load.

Sine components of wave $f(\varphi) = \sum_{i=0}^{i=\infty} x_1 \sin i x$	Cos. components of wave $f'(\varphi) = \sum_{i=0}^{i=\infty} y_1 \cos i x$
$x_1 = +106$	$y_1 = -13.9$
$x_3 = -19$	$y_3 = +3.6$
$x_5 = -3$	$y_5 = +8.8$
$x_7 = +2.3$	$y_7 = -1.1$
$x_9 = -1.9$	$y_9 = +1.0$
$x_{15} = -2.1$	$y_{15} = -.7$

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waves contain numerous inflection points and would require eight respectively twelve applications of different exponential functions. That is a complexity which it would be useless to attempt to untangle. Expressed in Fourier's series, however, the wave contains a moderate sized triple harmonic, a strong quintuple, and a moderate sized septuple harmonic, while all the higher harmonics are negligible.

The waves in Figs. 3 and 4 can be expressed by four terms only, namely:

No load: $\sin \varphi - .12 \sin (3 \varphi - 2.3) - .23 \sin (5 \varphi - 1.5) + .134 \sin (7 \varphi - 6.2)$,

25 amperes load: $\sin \varphi - .176 \sin (3 \varphi + 11.7) - .085 \sin (5 \varphi - 33.8) + .01 \sin (7 \varphi + 26.6)$.

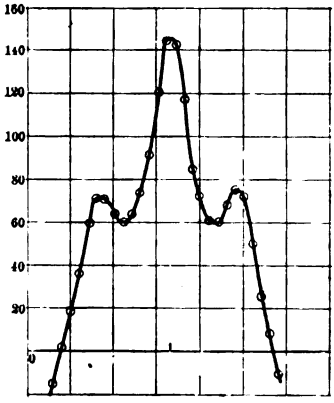

FIG. 5.

No load.

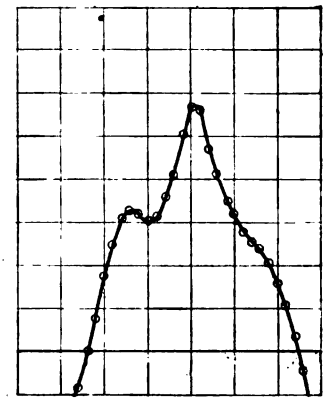

FIG. 6.

25 amp. load at 2,000 volts.

Potential waves A.T. 12 — 150 — 600.

Their complete expression is:

No load: $\sin \varphi - .12 \sin (3 \varphi - 2.3) - .23 \sin. (5 \varphi - 1.5) + .134 \sin (7 \varphi - 6.2) - .002 \sin (9 \varphi + 27.7) - .046 \sin (11 \varphi - 5.5) + .031 \sin (13 \varphi - 61.5)$,

25 amperes load: $\sin \varphi - .176 \sin (3 \varphi + 11.7) - .085 \sin (5 \varphi - 33.8) + .010 \sin (7 \varphi + 26.6 - .009 \sin (9 \varphi + 39.5) - .020 \sin (15 \varphi + 130.8)$.

The waves in Figs. 5 and 6 are the sum of two of the waves 3 and 4 displaced by 60°.

From all this you can easily see how utterly hopeless the attempt must be to express such waves by empirical exponential functions.

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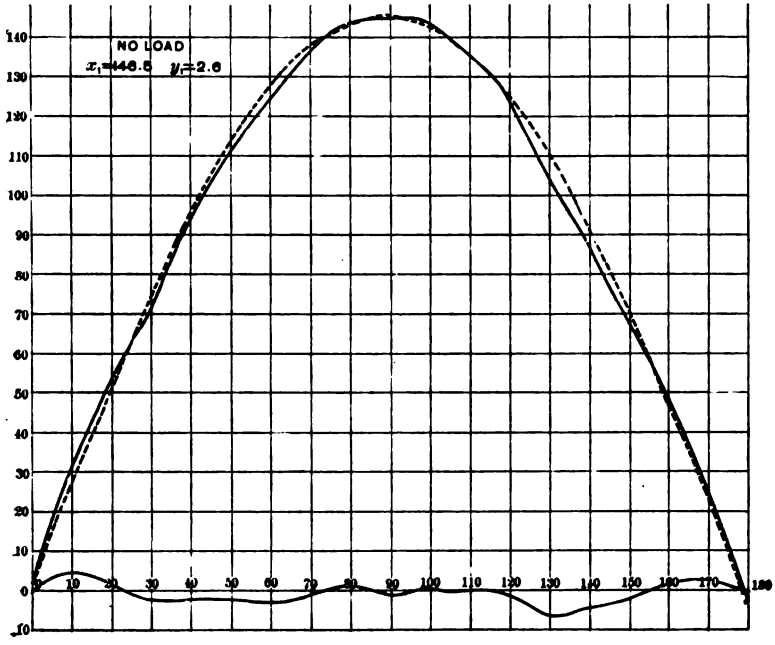

FIG. 7.

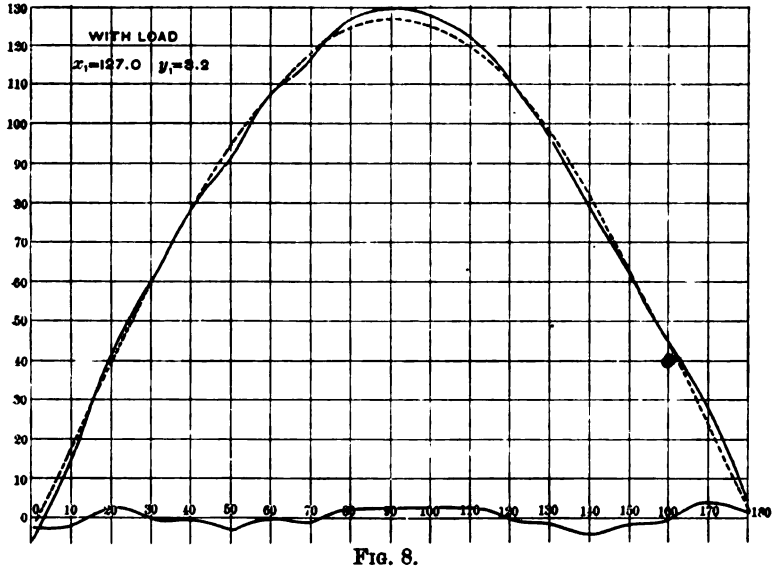

FIG. 8.

Analysis of Alternator Waves.
Polytooth Threephase Machine A.P. 12 — 300 — 600.
3 slots per pole and phase. E. M. F. at no load and load.

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Dr. Emery :—We are to be congratulated that this discussion has induced Mr. Steinmetz to show a number of interesting curves from novel machinery recently developed, and the adaptation of the Fourier series to the same. For present purposes, however, it should he noted that the same results would have been obtained by somewhat similar combinations of other than sine curves. The painter, to produce his effects, puts a particular color over a particular area, another color over another area, and so on until a representation of the desired object is secured with sufficient accuracy for the purpose. Any curve can be represented and formulated by similarly applying at proper intervals representing time, a sufficient number of known curves of proper sign and amplitude, and the equation of the original distorted curve will be the sum of the equations of the regular curves. It is not necessary to be confined to a sine function. Any function can be employed which will represent the conditions that cause the particular distortion. If, as Mr. Berg and Mr. Steinmetz appear to show, the changes in reluctance due to toothed construction indicate the selection of a particular harmonic, they would also show the manner in which any other curve should be applied. We only claim that it is much more rational to find the elements of the applied curve from the conditions instead of assuming a sine curve, and this is what is meant in the paper (§ 66) by "imposing upon the original function another function based on the actual conditions which produce a certain change." The general method is the same in each case. The whole is built up from various parts. The particular equations used in this first presentation of the method are especially valuable, for the reason that they represent so many different forms of curves by a simple change of the exponent, but the very act of imposing conditions mathematically on such curves would immediately change their shapes. If the experimental curve had points of inflection the representative curve would also have the same. The mere application of one curve upon another, so to speak, as the artist puts on his color, is mechanical, empirical, or whatever it may be called, *in either case.* The selection of the particular curves thus combined is certainly empirical if it be assumed in the first place that all are sine curves, and the operation can only be made rational by formulating the conditions which produce the change. The trajectory of a projectile could be represented by combining a series of sine curves by the Fourier method, but everybody knows that the underlying functions are not duplications of a sine curve, but a combination of simple functions which give as a resultant practically two parabolas combined to form an unsymmetrical curve.

The committee on resolutions then submitted the following report, which on motion was adopted.

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To The American Institute of Electrical Engineers.

Gentlemen :—Your committee appointed to draft resolutions regarding the courtesies extended to its members during its Niagara Falls meeting, beg to submit the following preamble and resolutions as its report :

Whereas, the American Institute of Electrical Engineers at this its 98th regular and 12th general meeting assembled at Niagara Falls, June 25, 26, 27 and 28th, 1895, has received many courtesies and privileges from various interests identified with the City of Niagara Falls, and as the Institute has appointed the undersigned committee to voice the expression of the Institute's appreciation, it is hereby

Resolved, 1st, that the American Institute of Electrical Engineers feels a deep sense of gratitude for the courtesies extended to its members collectively and individually, and believes that the privileges thus bestowed have in no small degree contributed to the success of our meeting and the enjoyment of our members.

Resolved, 2nd, that the thanks of the Institute be and they are hereby extended to the Niagara Falls Power Co., the Cataract Construction Co., the Westinghouse Electric & Manufacturing Co., and their officers and employees, for their kindness in opening their unequalled power station and works, and to the General Electric Co. for opening their converting plant for utilizing power at the works of the Pittsburgh Reduction Co., for the inspection of the members and guests of the Institute, and for their full and cordial explanation of those most interesting plants.

Resolved, 3rd, that the thanks of the Institute be and they are hereby extended to the Niagara Falls Light and Power Co. and the Niagara Falls Paper Co. for the opportunity afforded for the inspection of these companies' plants.

Resolved, 4th, that the thanks of the Institute be and they are hereby extended to the American Telephone and Telegraph Co., for the generous offer of the free use of its long distance lines to all parts of the United States, and to Capt. Brinker for opening the Falls Observation Tower to members and guests of the Institute.

Respectfully submitted,

B. F. Thomas, Chairman,
B. J. Arnold,
W. J. Hammer,
Committee.

The Secretary announced that Mr. Brackenridge, one of the engineers of the Cataract Construction Company, had placed at the disposal of members of the Institute and guests a special train from the power-house through their model village (Echota) and over the grounds of the company, for three o'clock this afternoon.

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A paper presented at the 12th General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 28th, 1895. President Duncan in the Chair.

EXISTING COMMERCIAL APPLICATIONS OF ELECTRICAL POWER FROM NIAGARA FALLS.

BY W. L. R. EMMET.

The first arrangements which were made by the Niagara Falls Power Company, for the commercial application of the electric power of Niagara Falls were with the Pittsburgh Reduction Company for the delivery of direct current for the manufacture of aluminium by their electrical process. In this process the cost of power is an important factor, and it is therefore naturally one of the first industries which we would expect to find attracted by the great advantage offered by this town. The contract made with this company requires the continuous delivery of 1500 electrical horse-power in direct current at 160 volts. The aluminium process is a continuous one, and cannot be interrupted without serious loss, since the product is not perfect while the furnaces are being started, or when they are not in their normal working condition. It is therefore necessary that spare apparatus be always held in reserve, so that in case of accident the proper working conditions cannot be seriously interrupted. To fill these requirements the Cataract Construction Company has ordered from the General Electric Company the apparatus which is now installed in the Reduction Company's building.

This apparatus consists of four rotary converters, having a capacity of 400 K.W. each, and 8 transformers, each with a capacity of 200 K. W. The rotary converters are intended to be used three at once in parallel, the fourth being always in reserve. These machines transform two-phase currents at 115 volts into direct current at 160 volts, the output of the three being 7,000 amperes which will be delivered continuously.

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The stationary transformers are designed for a primary voltage of 1000 and a secondary voltage of 115, their function being to reduce the current generated in the main power station, to a suitable pressure for conversion into the desired direct current. In addition to the rotary converters and transformers, the General Electric Company has furnished switchboards, conductors, cooling apparatus, cables to connect the plant to the generating station and all the necessary accessories.

Rotary Converters.

The rotary converters installed, are of 20 poles, and are operated at 150 revolutions per minute, giving a frequency of 25 cycles per second. The armature is of the smooth body type, having a cylindrical winding of conductors formed of pressed stranded cables. These cables are made up of small bare copper wires loosely twisted into a strand. This strand is then placed in a die under a powerful press and is pressed into a rectangular form, the wires being so pressed together that the cable has practically the same effective copper section as a solid bar of the same size. In spite of this pressing together of the wires, we find, by experiments, that parasitic currents are practically eliminated by this form of construction. On each side of the laminations of the armature there are cylindrical extensions for the crossings of the armature conductors. The whole winding is on a cylindrical surface, the ends of the stranded cables themselves being jointed together at the outer edges of the extensions. This machine has a small armature reaction, 5,500 ampere-turns per pole, and has an average potential difference between commutator bars of 3.6 volts. Copper gauze brushes are used, there being 20 studs with three brush-holders per stud. The brushes are shifted and raised from the commutator all at once by hand-wheels. The field frame of the machine is cast-iron, and the magnet cores and pole-pieces are of cast-steel. The cores are made in spool form, there being an enlargement at one end to form the pole-pieces and at the other, to increase the area of contact with the cast-iron. The base is in a single casting with the pillow blocks, giving rigidity and alignment. The commercial efficiency of these machines is about 94 per cent. [See Fig. 1.]

The stationary transformers used in the plant are of 200 K.W capacity each, eight being used in all. They are kept from injurious heating, by currents of air delivered from below, which

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passes upward through the body of the transformer, and over the surface of the coils. Both the laminations and the coils are built with spaces for the circulation of air, and the space pieces in the iron are so arranged that the air will follow the paths where it will do most good. The transformers are placed in the room

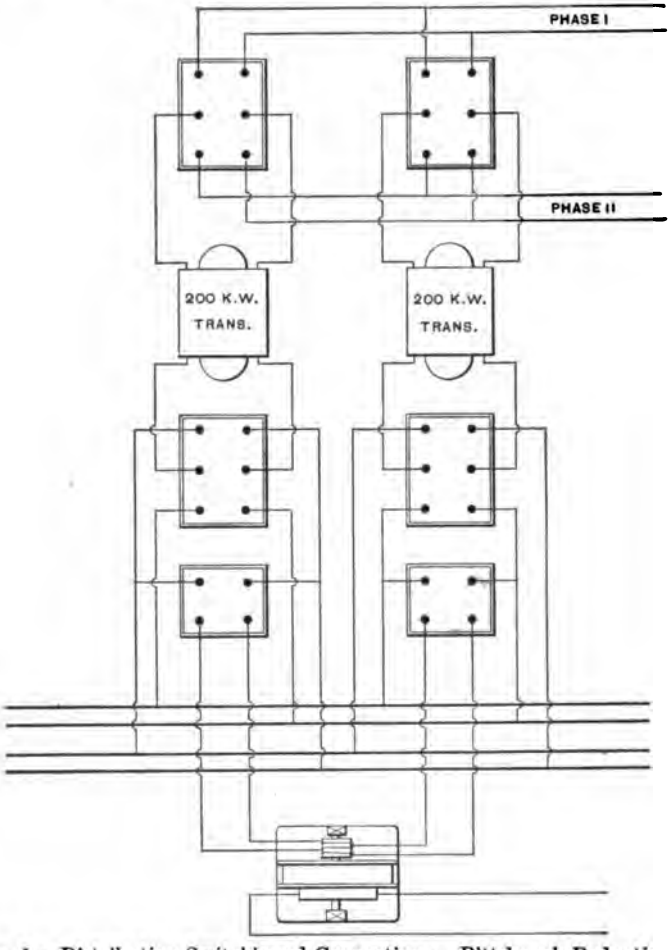

FIG. 1.—Distributing Switchboard Connections. Pittsburgh Reduction Co.

without casing or covering, so that much of the heat is carried away by radiation, and by convection of the outside air. The construction of these transformers, will be clearly understood when they are examined as they stand in the Pittsburgh Reduction Company's building. The laminations are held between

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two cast-iron frames, by bolts and side frames, which hold the whole structure rigidly together. The weight of the laminations is borne by two pieces of "I" beam, held between the end frames, on which the edges of the punchings rest. These "I" beams also serve to form a compartment under the transformer into which the circulating air is delivered. There are four primary and five secondary coils in the transformer alternately placed with

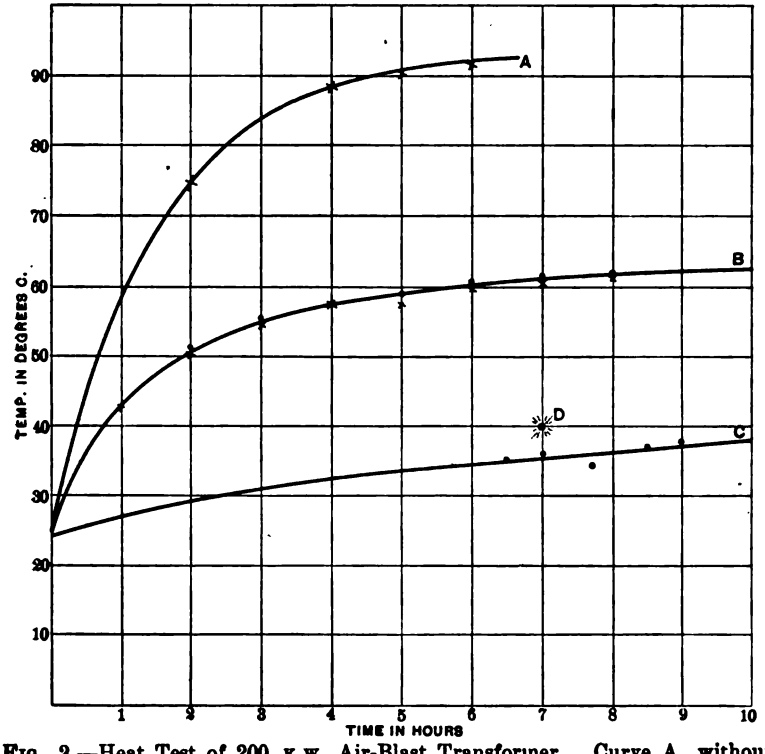

FIG. 2.—Heat Test of 200 K.W. Air-Blast Transformer. Curve A, without blast. Curve B, blast 1040 feet per minute. Curve C, air issuing from Transformer. Point D, laminations after 7 hours with Air-Blast at 1040 cu. ft. per minute.

air spaces between them. This arrangement gives ample cooling surface, and freedom from magnetic leakage. The accompanying curve shows the temperature of one of these transformers when run at full load, with an air-blast of 1,040 cubic feet per minute, requiring a power of about one-quarter of one per cent. of the transformer. The temperatures here given are taken by resistance measurement of the coils. It will be observed that the effect

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of the air-blast is very great, the maximum temperature being practically reached in three hours. The curve also shows that if the air-blast was stopped when operating under normal conditions, about three hours would elapse before a dangerous temperature was reached. [See Fig. 2.]

The air for cooling transformers is conveyed to them through a large duct or covered trench above which they are placed. This space is formed by an excavation in the floor, with brick retaining walls, and is covered by iron plates flush with the floor, all being made practically air tight. The plates on which the transformers stand, are provided with openings in the form of grids with slide valves, by which the admission of air to the transformer can be regulated at will, or shut off altogether. The air is supplied by

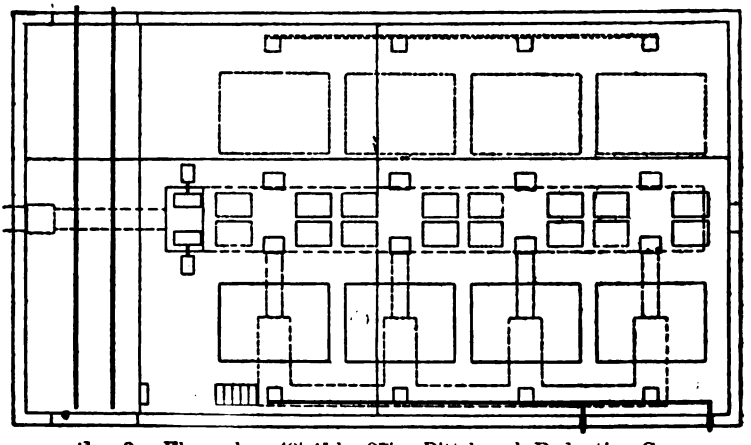

FIG. 3.—Floor plan, 48' 4" by 87'. Pittsburgh Reduction Co.

a 60-inch Sturtevant blower, directly coupled to a five-H.P. motor. Two of these are installed, one as a reserve. Either will give sufficient air to cool 3,000 H.P. in transformers.

The room in which this apparatus is placed is 48'x87', and is designed and arranged to receive apparatus to the amount of 4,000 H.P. Only half this capacity is now installed. This plan was laid out with a view to the occupation of a minimum space, and although the machines are large for their output, it fairly illustrates the compactness attainable in a plant of this characters Figure 3 is a floor plan of the room.

The system of conductors and switches in this plant is so arranged that every piece of apparatus is readily interchangeable with every other, so that the spare pieces are always ready in ace.

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of trouble, no matter where the trouble may occur. This, as I have said, is made imperative by the nature of the reduction process in which a shut-down entails heavy loss. The arrangement of conductors and of apparatus is such as to require about the minimum amount of copper under the circumstances. The air spaces below the transformers contain all the conductors connecting the transformers together, and to the outside lines. The conductors from the switchboards on the alternating side of the machines lead downward into the air chamber, the conductors from these boards to the machines lead through open ducts covered by floor plates. On the direct current side of the machine an open passage is left under the floor, which serves as a means of getting at the lower brushes and also provides space for the cables and wiring. The direct current switchboards are placed above this passage, and the terminals from their backs are bolted directly to the 'bus bars which deliver the current to the Pittsburgh Reduction Company's furnaces.

With some machines of this class there is no difficulty whatever in starting, while with others it is impossible to start from the alternating current alone. The machines here installed, will start from the alternating current and come up to synchronism promptly. After one machine is in motion, the others will be started from the direct current side, a set of connections and a resistance box being installed for that purpose.

In throwing machines of this character into parallel, great care must be observed. We must be sure that they are exactly in synchronism, and also that the direct current polarity is the same. To accomplish this we have arranged a system of phase lamps, by which both these points are shown. Each machine is fitted with 7 lamps which are required for lighting the room and the machine. Four of these are on the collector side of the machine and are so arranged by switches that they can be connected as phase lamps, two on each side of the two phase system between the machine and the alternating 'bus bars. When all four lamps burn together and the fluctuations of the light become very low, the machine is ready to throw in. If through misplaced switches or wrong connections the polarity of the machine and alternating circuit do not agree, two of the phase lamps will burn while the others are out.

The General Electric Company has installed four 900,000 C. M. cables which connect this plant with the main generating station.

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These cables are lead covered and insulated with rubber. They are jointed inside of the Reduction Company's building to small cables which lead to the switchboards near the transformers.

Another of the important contracts closed by the Niagara Falls Power Company for the delivering of electric power from the Falls, is that with the company which manufactures the substance which has been given the name "carborundum." This substance is carbide of silicon; it is of extreme hardness and is used as an abrasive in the same manner as corundum or emery.

This substance is manufactured from a mixture of sand and coke by the application of heat derived from an electric current. The ingredients are mixed together and piled in a furnace between two large carbon electrodes. A current is then passed through the mass which gradually heats. After a high temperature is attained, the carbon and silicon begin to combine, and the

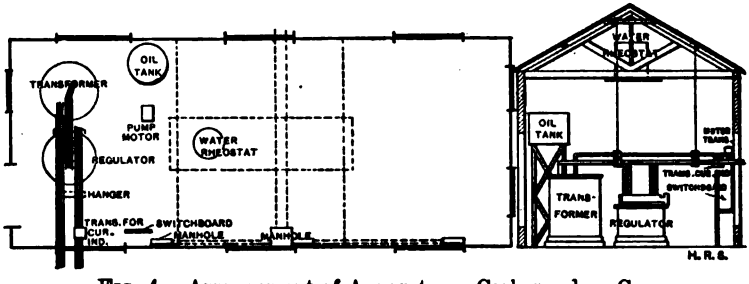

FIG. 4.—Arrangement of Apparatus. Carborundum Co.

product collects in crystals on the cooler external surface of the mass. After the process has gone on for about 24 hours, the current is stopped and the mass allowed to cool.

The carborundum crystals are found in a loose crust on the surface. This process presents rather a peculiar electrical problem, since as the furnace heats, the resistance diminishes, and since it is desired to supply a given amount of power continuously to this falling resistance, the amount of power to be delivered in the present case is to be 1,000 H. P. The pressure required at the beginning of the process is 250 volts, and at the end 100 volts. The current begins at 3,000 and ends at 7,500 amperes. The power is to be taken from one side of the 2,000-volt two-phase system.

A number of different methods of supplying this power were proposed and discussed, and the contract for building the appar-

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atus was finally awarded to the General Electric Company, the fitness of the design proposed being, I believe, the principal ground for awarding the contract. [See Fig. 4.]

The chief merits of this apparatus are, first, it works without change of connection or opening of the circuit. Second, it is practically non-inductive at all stages of the process, the apparatus being so designed that the magnetizing currents are small, and self-induction is in no way depended upon for the control of the current. Third, the process is continuous, the voltage varying gradually, not in steps. Fourth, the apparatus is controlled automatically.

The apparatus consists in a transformer and a regulator. The former has a fixed ratio of transformation, being built for an E. M. F. of 2200 in the primary, and 185 in the secondary. The regulation is virtually a transformer in which the mutual induction of primary and secondary is variable. Its design is somewhat similar to that of an induction motor, there being two concentric parts built of laminations with distributed windings in slots on each. The outer member is fixed, while the inner is movable through an arc of 60°. This angle corresponds to the space between two poles, the windings being so grouped as to form six poles.

In addition to the regular windings, the movable member is fitted with closed turns of low resistance between the poles, so placed as to prevent magnetic short-circuiting when the regulator is in or near mid-position. Thus the regulator is a transformer in which the inductive relation of the two coils is reversible, and in which the mutual induction is variable.

The connections of the transformer and regulator between the line and furnace are shown in Fig. 5. The regulator there appearing has, for the sake of simplicity, been shown with two poles only, and of Gramme construction, while six poles and cylindrical winding are in reality used.

The transformer and regulator will be connected together and to the furnace by heavy copper bars, suspended above them from the roof of the building. The winding on the stationary part of the regulator is placed in series with the transformer secondary, and that on the movable part is in shunt. The conductors at different points are proportioned to the currents which they carry. Eight bars, 4″ x ½″ of suitable lengths, give the desired arrangement.

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The transformer and regulator are cooled by circulating oil. A pump and two tanks are used, one above the other. The upper tank contains a coil of pipe in which water circulates. It is so arranged that the moving oil must flow over this coil and give up its heat. The lower tank receives the oil from the apparatus, and prevents an overflow in case the pump stops.

In the transformer, the oil is admitted at the bottom, and flows upward through and around the coils, the coils being placed vertically and the laminations horizontally. After overflowing at the top of the coil space, it finds its way downward over the outer

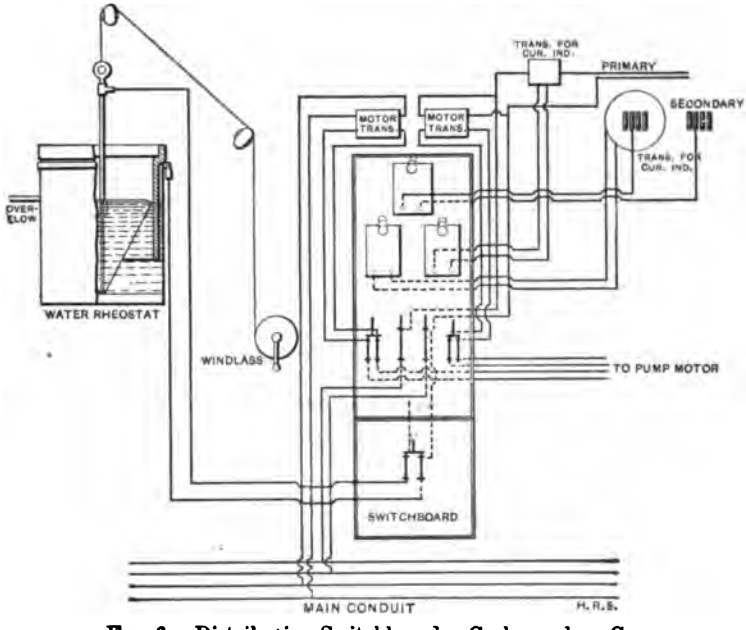

FIG. 6.—Distributing Switchboard. Carborundum Co.

surface of the laminations. The regulator is so constructed that it revolves in a horizontal plane. The cooling oil flows upward through the air-gap between the two parts, and down over the outer surface of the stationary part, and inner surface of the movable part. The transformer is placed in a cylindrical tank, while the regulator is self-contained, the cast-iron supporting shell forming the outer casing.

The oil is lifted by a small induction motor geared to a pump. Since the process is not continuous, some means of opening the circuits must be provided so that the apparatus may be cut out

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when the process is complete. The arrangements which have been made for this purpose are shown in Fig. 6. A pair of large snap switches is placed, one in each lead from the generating station. In parallel with one of these switches a specially designed water rheostat is placed. This rheostat consists of an iron tank lined by a section of vitrified pipe of large diameter.

This tank is about half filled with water, and a pointed electrode is so arranged that it can be raised or lowered from the water by a rope leading to a small winch. Before the switch is opened, the electrode is lowered into the water, which provides a non-inductive circuit in parallel with the switch. After it is opened the electrode is raised, which increases the resistance till the circuit is broken at the surface of the water. The vitrified pipe prevents the possibility of arcing or contact between the electrode and the iron tank.

A switchboard will be installed on which the switches will be mounted, also the switches for controlling the pump motor. Current indicators will be mounted on this board which show the current in the primary leads, also the current passing to the furnaces. These indicators will be operated from small transformers which encircle the conductors. A voltmeter will also be installed which will show the E.M.F. at the furnace terminals.

This plant will for the present be operated by cables branching from those leading to the Pittsburgh Reduction Company's plant.

Discussion.

Mr. Jules Neher:—We have all had an opportunity of visiting the transformer house of the Pittsburgh Reduction Company, and certainly we all have admired the beautiful workmanship and the imposing size of the apparatus described. I am peculiarly interested in these machines, and therefore would like to be permitted to put a few questions to the parties who were connected with their construction, in the hope of receiving a few pointers. I know by actual experience that a revolving converter can be rated at about 130 per cent. of a generator of the same dimensions, owing to the fact that a part of the current goes directly from the collector ring to the commutator without in fact making use of the armature winding or the boosting effect of the armature winding.

The machine to act as a revolving converter is a synchronous motor, and as I also know by experience, the synchronous motor works better in synchronism if there is a certain flywheel effect to it. I think it is cheaper to make a smaller flywheel running at a high speed than to make a large flywheel running at very slow

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speed. This is the second point. Another point: In a machine where we have very many poles, the sensitive part of the commutator is very much smaller naturally, or extends over a very much smaller angle than on the machine with a few poles, where the neutral point extends over an angle of quite a number of degrees. This naturally has been overcome by the use of very many comtator bars, as is done on the Siemens-Halske machines; but on a machine for reducing purposes where the load varies very much, and often varies suddenly, it seems to me that the sensitiveness of the commutator is a very important point. I would therefore like to know just why the number of poles, or why the machine in this respect was planned so large. In looking at the 5,000 H. P. generators running at a speed of 250 revolutions with a 12-pole field, it naturally is striking, why a secondary machine which has no strains on the shaft, which, in fact, is only a revolving fly-wheel, should have the exceedingly slow speed of 150 revolutions and a 20-pole field. I have compared these revolving transformers with the one in the power-house back of the switchboard structure, which is to be used as an exciting machine for the generators. Now this small machine has a capacity of 200 K. W., and runs at a speed of 500 revolutions, while the Pittsburgh Reduction Company's transformers have a capacity of 375 K. W. and are about ten times as large. I also have compared these machines with the direct current generators, of say 1,000 H. P., running at the Corliss engine speed, or about 80 revolutions. Now I have seen machines of this type which are about the same size and weight as the Pittsburgh Reduction converters, but with double output and about half the weight, which would make these machines practically four times smaller. I would be very happy if I could get an idea why these large dimensions were chosen, not only on account of the slow speed, but even compared with other slow speed machines, which, as I just stated, are about one-quarter the weight.

MR. EMMET:—The building of direct current dynamos is something which is considered by a great many people a very simple matter as compared with some of the other problems in electrical work. It, however, is a fact, that the design of the direct current machine is a matter of more complexity than anything else that we have in electrical science. For certain kinds of machines, at certain speeds, and certain outputs and certain voltages, the problem is very simple and a good result is certain. Under other conditions a good result is extremely difficult to obtain. This is particularly true of large machines. A very considerable proportion of the large direct current machines which have been built have been failures to a greater or less extent, and this has been particularly true in machines which were operated with copper brushes at low potentials. With rotary converters we have several additional conditions which still further complicate the problem. Even now there are very few rotary converters in opera-

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tion so that we have not much knowledge founded on experience. The machines in question were built, or designed, nearly two years ago. We have had them complete in our shops very nearly a year. I think there was on the part of the designing engineers, who are not here to speak for themselves, some misapprehension as to the uses to which these machines were to be put. A rotary converter can operate in many ways. It can fill many functions. It can compound for losses in the line, and it can operate with considerable variation of secondary E. M. F.

It is my belief that our engineers, knowing that the machines were being designed for an electrolytic process, were apprehensive as to the effect of sudden fluctuations of load on the maintenance of constant potential. The specifications on which this contract was closed, recited at very great length what the machines should do. The specifications were prepared by the engineers who designed the machines, some time before the contracts were closed, and they were possibly based on a slightly wrong impression as to what the machine should do. We were anxious to live up to those specifications exactly, and the result was the machinery as it stands.

The efficiencies warranted in these specifications were so high that copper brushes were a necessity. The loss with carbon at such low potentials is considerable. The present machines requiring something in the neighborhood of 80 or 100 square inches of carbon surface to take off the current, the heating effect of this on the commutator would be great. A copper brush being decided on, it was thought desirable to make a very low armature reaction in the machine, and to get a low armature reaction with the necessarily low voltage per bar, a large number of poles was indispensable. So by the operation of a system of reasoning which I cannot fully explain at present, but which in the mind of the designer was undoubtedly sufficient, the present form of machine was adopted. It is a large machine for the output, simply because its speed is low.

Since these machines were built, we have designed other rotary converters for the purpose of making propositions on similar work. Of these, some have been copper brush and some carbon brush machines; but they all have been smaller than the ones under consideration now. We have also built several three-phase rotary converters of the same output as these machines which are now in operation and giving excellent results.

The exact ratio between the output of a machine as a rotary converter, and as a direct current generator, cannot be stated definitely. It is one that must depend very much upon circumstances and what the rotary converter is to do.

MR. NEHER:—I am, indeed, thankful for the information obtained from Mr. Emmet. I did not touch at all upon the point of the copper brushes, although I think, as Mr. Emmet has explained to us, this was one of the leading points which determined the size and the number of poles in that machine. As to the use

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of common copper brushes in general for electrolytic machines, I can say that I have seen a good deal of it. I think I have seen the largest electrolytic machines that are in operation, that is at the aluminium works at Neuhausen, Switzerland, where there are machines directly connected to turbines, vertically, which deliver 7,500 amperes at 60 or 70 volts. These machines have 24 sets of copper brushes, and it requires the attendance of a man at each machine continuously, to attend to those. It was found impossible there to use carbon brushes on account of the enormous length of the commutator which would have been necessary; though since then, I have seen the same difficulty overcome in the present machines of the Pittsburgh Reduction Company, and in fact on two old machines, vertical bipolar machines, which had been operated with copper brushes, and very heavy copper brushes, about three-quarters inch thick, and where the copper was ground off at the rate, I think, of between $100 and $200 worth per month. There the copper brushes were replaced by carbon brushes, and, interesting to say, by carbon brushes which stood lengthwise with the direction of rotation covering the commutator over a space of about 2½ inches. I saw these machines operate after that, beautifully and without any loss at all. The commutator stood for years and the expense in brushes was nominal.

As to the design of these large converters with carbon brushes, I do not think it would have been impossible, though naturally the whole arrangement of the machine would have become entirely different. As much as I have seen of large generators with copper brushes in the various Edison electric light stations, and of Siemens' make, the machines most assuredly can work perfectly with copper brushes, and I believe that the rotary converters in this station will work perfectly well.

Mr. Steinmetz:—When comparing these large converters revolving at a very low speed at the Pittsburgh Reduction Company's works, with the small rotary converter running at very high speed as exciter in the power-house, it is quite remarkable how much larger for their output the former machines are. However, the reason for the design adopted in these machines lay in the particular nature of the work required from them, in which it is of the utmost importance that the machines shall never shut down, but run continuously for months and months. For this reason it was considered advisable to use the utmost conservatism in their design. If instead of using an average difference of potential of 3½ volts per commutator bar, it had been deemed safe to operate them at 15 volts average potential between commutator bars, and carry 2,500 amperes off by carbon brushes, it is obvious that a smaller number of poles and thus a smaller machine might have been used. However, this was not considered desirable, but we rather preferred to put more material in the machines and be perfectly safe.

Besides, another point has to be taken into consideration.

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Polyphase continuous current machines can fulfil either the function only of converters from alternating to continuous current, or can operate not only for conversion from alternating to continuous current, but also to control the potential.

If a machine is intended only to receive the alternating current at whatever voltage it may be impressed upon it, convert it into continuous current and supply continuous current at whatever voltage corresponds to the alternating current voltage which happens to be impressed upon the machine, then the machine can be much smaller than a continuous current dynamo of the same output, or in other words, a given machine can be rated at a higher output as alternate continuous current converter than as continuous current generator, since the alternating current and the continuous current in the armature flow in opposite directions, and thus the current-heating of the armature is due to their difference only, while at the same time the demagnetizing effect exerted upon the field, and the distortion of the magnetic circuit are essentially reduced. Under these conditions the output may be twice as large or even still larger compared with that of the same machine as a continuous current generator.

However, the conditions are different, if besides, a potential control is required from the machine, that is if the machine shall supply constant continuous current potential at the commutator brushes independent of the alternating voltage, within a certain range, which is impressed upon the machine. In this case, by the reaction of the alternating armature current upon the field, which varies with the varying phase relation of the alternating current, and by self-induction, the potential can be controlled so as to maintain the continuous current potential independent, to a certain extent, of the alternating current potential. In such a case the rotary converter must be considerably larger, and be practically of the same size as a continuous current generator of the same capacity.

If I remember rightly, when the question of designing these machines was brought up—it is so long ago that I have nearly forgotten it—we were told that the machines should deliver 160 volts continuous potential, while taking power from a high potential alternating circuit varying from 2,000 to 2,400 volts. This means a variation of alternating current voltage of 20 per cent. had to be controlled by the converter, and for this reason they had to be made as large as you see them. Had it not been for this requirement, we would have designed them considerably smaller.

Regarding the last point, the required flywheel capacity, I cannot agree with the speaker that a flywheel is necessary in a synchronous motor. On the the contrary, in some cases large flywheel capacity is directly objectionable, as in starting a synchronous motor. In starting, the less momentum you have, the quicker the machine will start, and with a heavy flywheel it may not be able to start at all satisfactorily without any external means

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However, under certain circumstances, flywheels may be necessary, especially with machines with weak and unstable magnetic fields which will tend to fluctuate. In this you need a flywheel to steady the motion. In general, however, this is not necessary, and, as far as my experience goes, I never found a case where I required a flywheel to hold a synchronous motor in step.

Mr. Neher:—We certainly find that at slow speed a large armature will have a flywheel effect, and will never be unsteady, and the idea will never strike any one that this machine ought to be kept more steady. In making small revolving transformers though, I think everybody has met with the difficulty of getting the machine to run without pumping. The revolving transformer which has not exactly the same E. M. F. curve as the generating machine, will tend to pump, and if there is a little of that flywheel effect of the armature, this pumping becomes objectionable; in fact, I have experimented with a revolving transformer which I could not hold in step at all. As to the question of starting, I think this has been explained already, because the Pittsburgh Reduction converters are going to be started from the outside. Although, as this point has been touched upon, I would be glad to get some explanation of it, because as far as I know, revolving converters on two-phase currents are started with extreme ease from their own alternating circuit.

Mr. Stillwell:—It appears to me that some of the members of the Institute might receive an impression, from the remarks which Mr. Steinmetz made, that the engineers of the Cataract Construction Company were not very confident as to the potential they should be able to deliver at the other end of their lines. The fact which he has stated with reference to the specifications submitted to the engineers who designed the rotary transformers is new to me, and illustrates the difficulties under which the system here at the Falls has been designed and installed. The specification that the generators should be able to deliver their full output at any potential between the limits of 2,000 and 2,400 volts, was suggested by our company for this reason: That, looking forward to the time when the machines should be called upon to deliver power for transmission to long distances, we foresaw that it would be necessary to develop in one set of generators used for the long-distance service a higher potential than that used in the other set of generators used for the local circuits. The intention from the start, and the confident assurance of all the engineers concerned in the work, has been that we shall be able to deliver for the local circuits a potential closely approximating 2,000 volts, and for the Buffalo service, or service in still more distant points, the same potential. I understand, from Mr. Steinmetz's remarks, that the specification which the Cataract Construction Company laid before the engineers who designed these rotary transformers, was not properly drawn, and was so stated as to impose upon them very considerable difficulty in the

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design. I am interested in the explanation of the exceptionally large size of these machines; but if the specifications had been clearly understood among all concerned, there would have been no reason why they need have been built of increased size in order to act as regulators for the system.

MR. EMMET:—I would say in connection with this that there is a possible misunderstanding. At the time when these propositions were being received and this contract was being closed, the Westinghouse Company had a little bit the advantage of us in the matter of communication with the purchasers, because Mr. Stillwell, as engineer, was communicating with them, and he obtained a correct idea and would have acted upon it undoubtedly. Our engineers were not in direct communication with the Cataract Construction Company, and some misunderstandings undoubtedly crept in. I tried to look up the history of the case but I find that it is impossible to trace it exactly. If the specifications, written or verbal, introduced practical difficulties, I admit there would have been no trouble whatever in getting those difficulties out of the way, since the Cataract Construction Company has always been perfectly willing to accept our advice, and has generally allowed us to do work in the manner which we thought best. I think, however, that in this case there was some misunderstanding, and that appeal was never made, because our engineers thought they were tied down to certain conditions and could not avoid them.

MR. STEINMETZ:—I would like to take up the question of flywheels once more. The statement that a synchronous motor tends to hunt if the wave of impressed E. M. F. is different from the wave of counter E.M.F., does not agree with my experience. I have run small machines as rotary converters of ½ H. P. and 1 H. P., as well as large machines of 400 K.W., and have operated them from machines giving wave shapes entirely different from that of the rotary converter. The rotary converter gave practically a sine wave, with a very small flattening at the top, while the generator, for instance, in one case was a monocyclic machine with a wave shape as mentioned in the last session, containing a triple harmonic of about 24 per cent., and in another case I used as alternator a three-phase machine with a triple harmonic of 12 per cent., a quintuple harmonic of 23 per cent., and a septuple harmonic of 13 per cent., and did not find any tendency whatever to hunt or behave unstable, except in one case where a small rotary converter was highly over-excited and thereby became unstable.

Regarding the starting of these machines, when connecting them directly across the mains while at rest, as is most desirable for getting a quick start and avoiding the necessity of rheostats and other complications, in such a case the starting current is about 1½ to 3 times the rated or full load current, and the machine runs up to speed from absolute rest in from a few seconds to several minutes time.

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MR. NEHER:—This flywheel is a slight curiosity, but I think that the flywheel effect has to be secured, and rather in the shape of cast-iron than of expensive armature and commutator-copper, and this is why, on the power-house converter, that small extra flywheel is to be seen, while on the reduction converters all the flywheel is in the armature itself, and none to be seen outside of it.

I do not agree with Mr. Steinmetz in the statement that a very small revolving converter, running on a different curve than the generator will not pump, because I have seen them pump, and do so with any possible adjustment with any of the field. I have seen them pump with a low field and I have seen them pump on all the steps of the excitation. It may be that this was on account of the special designs of the machines, which were not designed as revolving transformers.

As to the flywheel on the machine which is now in the power-house, I would like to say that this machine has such an exceedingly small armature, of so exceedingly small diameter, although it runs with a speed of 500 revolutions, that the flywheel effect of this machine can in no way amount to the flywheel effect of one of the armatures in the Pittsburgh Reduction power-house; and therefore I still maintain that in those big machines the flywheel effect was secured by a slow speed and very large diameter. I simply think it is cheaper to secure it by high speed and small diameter.

MR. STEINMETZ:—I think I can explain the discrepancy between the observations made by me, and those made by the last speaker in regard to the hunting of the machines. The machines I observed were not specially built as rotary converters either, but were standard continuous current motors or generators changed to converters. Still I did not notice any hunting. But most of my experience was limited to three-phase machinery, while the last speaker probably got his experience from quarter-phase machines. Now, if you examine the effect of the higher harmonics, especially that of the triple harmonic, which is generally the most pronounced one, you will see that in the three-phase system the triple harmonics coincide in phase with each other, and thereby annihilate each other in their magnetizing action upon the motor, that is, have no effect at all, while in the quarter-phase machine the triple harmonics combine in a rotary effort which tends to revolve the machine backward at triple synchronism. It was probably this effect which was noticed as hunting by the last speaker, in a quarter-phase circuit, but which does not exist in a three-phase circuit.

PRESIDENT DUNCAN:—This closes the programme of the Twelfth General meeting; a meeting which, for the number in attendance, and the interest displayed, gives great promise for the future of the INSTITUTE.

[Adjourned.]

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WESTERN UNIVERSITY OF PENNSYLVANIA.

ALLEGHENY, PA., APRIL 24th, 1895

PROFESSOR EDWIN J. HOUSTON, CHAIRMAN COMMITTEE ON INCOMPLETED CONGRESS WORK,
PHILADELPHIA, PA.

DEAR SIR: In reply to your request for a statement of the results obtained by me in regard to the work on standards of light and illumination, I would make the following report.

1. *Secondary Standards:*—The result of my work on incandescent lamps has shown that a set of two incandescent lamps, mounted so as to invariably have the same point turned toward the photometer spot, as faced it when the lamp was originally standardized, and worked at the same voltage as that at which the standardizing was done, can be used with very considerable accuracy for secondary standards. As mentioned in a previous report, one lamp is used for the photometric work, and the other is used as a check, and when the reference lamp has been burned a total of 200 hours, the set is to be discarded. The curve of fall of candle-power with life can be used for making corrections.

2. *Primary Standards:*—Work on the acetylene standard mentioned in a previous communication has been prosecuted under difficulties, as I had to make my experiments with barium carbide, and could, up to a week ago, obtain but small quantities of the gas. I have since been able to obtain a sufficient quantity, and have made numerous experiments.

So far, my attention has been given to the best means of keeping the gas at a uniform pressure, and on the best pressure to use. I have devised a convenient and satisfactory method of accomplishing the former, and enclose a drawing of the apparatus at present in use. As regards the latter, I find that a tolerably high pressure gives better results as regards constancy, than a low one, the pressure at present used being 12 inches of water.

By reason of the results obtained by Captain Abney, who showed that a flat flame gives a much more even illumination than a round one, I have been using a flat flame. The experiments so far made show a very constant illumination, and this without using a chimney.

The experiments about to be made will be on the following points—*a*. effect of impurities in the gas; (*b*) best means of obtaining flat flame; (*c*) possibility of accurately reproducing standard absolutely, by using slot of definite size and definite mode of generating and using.

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I may say that an appropriation of $800.00 has been made by the university for the purpose of making these experiments.

In conclusion, I would state that the acetylene standard appears to me to have the following advantages, provided that further experiments show it can be duplicated successfully.

1. *Use of definite chemical compound*, on the line suggested by Mr. Kennelly at the meeting of December, 1893. Even if different specimens of calcium carbide should be of different degrees of impurity, there is no reason to doubt but that these impurities can be absorbed, and pure acetylene left.

2. *It is self-contained*, the only materials used being calcium carbide and water, and no connection to gas pipes are necessary.

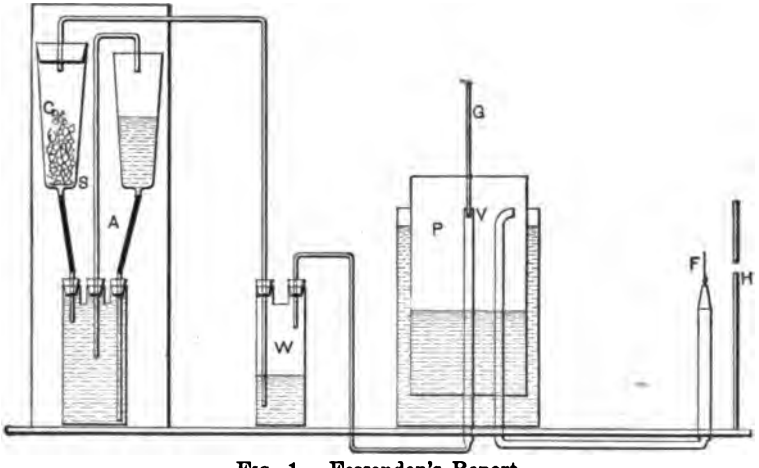

FIG. 1.—Fessenden's Report.

A. Generating Apparatus.
C. Carbide of Calcium.
S. Strainer.
W. Wash Bottle.
P. Gasometer.
V. Regulating Valve.
G. Guide Rod.
F. Flame.
H. Slot.

3. As the substance burned is of a definite chemical composition, and the dimensions of the slot and all the apparatus is capable of being accurately defined in terms of length and pressure, it seems to afford a method of obtaining an absolute standard.

4. *The light appears to be much whiter* than ordinary gas, which is a point of considerable importance in a standard. No exact spectro-photometric measurements have as yet been made, however.

I remain, very truly yours,

REGINALD A. FESSENDEN.

[Presented to Council May 21st, 1895, and ordered to be printed in the TRANSACTIONS.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, September 25th, 1895.

The 99th meeting of the INSTITUTE was held this date at the Hoffman House, and was called to order by President Duncan at 8 P.M.

The Secretary read the following list of Associate Members, elected by Council at its afternoon meeting.

Name.	Address.	Endorsed by
AUSTIN, SYDNEY B.	Electrical Engineer, Sidney, N. Y.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
BLAXTER, GEO. H.	Vice-President and General Manager, Allegheny County Light Co., Westinghouse Building, Pittsburg, Pa.	O. B. Shallenberger. Chas. F. Scott. Alex. J. Wurts.
BOYER, ELMER E.	Electrical Engineer, The Gen'l Electric Co., Lynn, Mass.	H. A. Foster H. Lemp, Jr. Elihu Thomson.
BURT, BYRON T.	Manager and Sec'y. and Treas. Charleston Light and Power Co., Charleston, S. C.	Geo. W. Davenport. E. W. Rice, Jr. A. L. Rohrer.
CARHART, HENRY S.	Prof. of Physics in University of Michigan, Ann Arbor, Mich.	M. I. Pupin. F. B. Crocker. B. F. Thomas.
CORNELL, JOHN B.	Supt. of Construction, with Chas. L. Cornell, Hamilton, O.	S. B. Fortenbaugh. B. J. Arnold. C. L. Cornell.
COSTER, MAURICE	Engineer Westinghouse Elec. and Mfg. Co., N. Y. Life Building, Chicago, Ill.	L. B. Stillwell. Chas. F. Scott. B. F. Thomas.
CRAWFORD, DAVID FRANCIS	Ass't to Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Chas. B. Dudley. F. L. Hutchinson. Leo. A. Phillips.
DAWSON, PHILIP	Associate and Chief Engineer, with R. W. Blackwell, 39 Victoria Street, Westminster, London, Eng.	H. F. Parshall, I. E. Winslow. R. W. Pope.

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DEGEN, LEWIS	Constructing Engineer, Gen'l Electric Co., Rio de Janeiro, Brazil.	John W. Kirkland, S. Dana Greene. Maurice Oudin.
DUNLAP, WILL KNOX	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	O. B. Shallenberger. C. F. Scott. L. B. Stillwell.
FRENYEAR, THOMAS C.	Gen'l Manager, Cayadutta Elec. Railway Co., Gloversville, N.Y.	E. N. Sanderson. T. C. Martin. C. J. Field.
HAKONSON, CARL HAROLD	Assistant Engineer, Gen'l Electric Co., P. O. Box 254, Schenectady, N. Y.	Chas. P. Steinmetz. Ernst Berg. H. G. Reist.
HARRISON, RUSSELL B.	Pres. and Electrical Engineer Terre Haute Electrical R'way Co., Terre Haute, Ind.	Ernest P. Warner. Henry H. Wait. Richard H. Pierce.
HARVEY, ROBERT R.	10 So. Franklin Street, Wilkes-Barre, Pa.	W. H. Powell. J. H. Klinck. Wm. J. Hiss, Jr.
HEWITT, CHAS. E.	Graduate Student in Electrical Engineering, Cornell University, residence Hanover, N. H.	Fred'k Bedell. Harris J. Ryan. Ernest Merritt.
HUNTLEY, CHAS. R.	General Manager, Buffalo Gen'l Electric Co., 40 Court Street, Buffalo, N. Y.	H. A. Foster. Ralph W. Pope. Wm. J. Hammer.
IRVINE, D. W.	Student in Electrical Engineering Lehigh University, So. Bethlehem, Pa. Residence, Chambersburg, Pa.	W. H. Powell. J. H. Klinck. R. W. Pope.
KER, W. WALLACE,	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant Street, New York City. Residence, 43 Waverly Street, Jersey City, N. J.	Jos. Wetzler. T. C. Martin. R. W. Pope.
LINCOLN, PAUL M.	Electrician-in-charge, Cataract Construction Co., Niagara Falls, N. Y.	B. F. Thomas. Chas. F. Scott. O. B. Shallenberger.
MANN, ROBERT BRUCE	643 Franklin Street, Milwaukee, Wis.	James Lyman. Alex. Macfarlane. J. D. E. Duncan.
MERRILL, JOSIAH L.	Ass't to Estimating Engineer of the Construction Department, Gen'l Elec. Co., Schenectady, N. Y.	Chas. P. Steinmetz. J. P. B. Fiske. Thorburn Reid.
MERZ, CHAS. H.	with Messrs. Robey & Co,, 38 Portland St., Lincoln, Eng. Residence, The Quarries, Newcastle-on-Tyne, England.	H. F. Parshall. I. E. Winslow. R. W. Pope.
MITCHELL, JAMES	Constructing Engineer and Agent, General Electric Co., Rio de Janeiro, Brazil.	John W. Kirkland. S. Dana Greene. Maurice Oudin.
MORLEY, EDGAR L.	Superintendent, Hatzel & Buehler, 114 5th Ave., Residence, 107 Lexington Ave., New York City.	C. O. Mailloux. J. C. Hatzel. F. A. Pattison.
PARRY, EVAN	Engineer, The British Thomson-Houston Ltd., 52 Glengarry Road, East Dulwich, London, S. E.	H. F. Parshall. I. E Winslow. R. W. Pope.

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PINKERTON, ANDREW	Electrical Engineer, The Apollo Iron and Steel Co., Apollo, Pa.	W. D. Weaver. Cecil P. Poole. Ralph W. Pope.
POWELL, PERCY HOWARD	Cornell University, Class of '95, residence, Hempstead, N.Y.	Harris J. Ryan. Ernest Merritt. Fred'k Bedell.
ROBINSON, DWIGHT PARKER	With Stone & Webster, Boston, Mass.. Residence, 100 Washington St., Chicago, Ill.	Russell Robb. Chas. G. Stone. Edwin S. Webster.
RUSHMORE, DAVID B.	Student in Electrical Engineering, Cornell University, residence, 168 Grove St., Plainfield, N. J.	Fred'k Bedell. Ernest Merritt. Harris J. Ryan.
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph-Cable Co., N. Y. City; residence, 703 President St., Brooklyn, N. Y.	Francis W. Jones. M. M. Davis. Jas. Hamblet.
STOTT, HENRY G.	Electrical Engineer, Buffalo Gen'l Electric Co., Buffalo, N. Y.	H. A. Foster. Jos. Wetzler. T. C. Martin.
WIESE, GUSTAV ADOLPH,	City Electrician of Alameda, 718 Haight Ave. Alameda, Cal.	Chas. T. Lindner. W. F. C. Hasson, Wynn Meredith.
WILSON, CHESTER P.	Sup't 33d and Market Sts. Power Station, Philadelphia Traction Co.; residence, 843 N. 41st St., Philadelphia, Pa.	Ernest Merritt. E. L. Nichols. Harris J. Ryan.

Total, 34.

Mr. Charles S. Bradley read the following paper on "Phasing Transformers."

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A paper presented at the Ninety-ninth Meeting of the American Institute of Electrical Engineers, New York and Chicago, September 25th, 1895.

PHASING TRANSFORMERS.

BY CHARLES S. BRADLEY.

On account of the large number of single-phase plants in existence which were built for lighting, and with no thought at the time of running motors from these systems, it has seemed to the electrical engineer very necessary to produce a single-phase motor. Many talented men have labored and studied upon this subject, and, so far, the results have not been at all satisfactory.

During the last few years the rapid progress of the polyphase motor has been the only success. The evolution of electrical art seems to be toward the production of apparatus which shall make all systems mutually convertible; so that we may be able to convert the phases produced, into a greater or lesser number; starting with a generator of three phases, we shall be able to produce from it two or one. Again, generating two phases, we shall be able to convert it into three phases or one. Again, starting with a single-phase generator, we shall be able to convert it into two or three phases.

The polyphase motor is so good as to need but very little, if any improvement, but this is so familiar to the INSTITUTE, that I need not go into details. I think the time is not far distant, when we shall be able to fill out with the alternating currents, any engineering problem that may be required of us. We will be able to take old plants and modify them to do any work which may be necessary. One of the important links to round out the art, seems to be the phasing transformer, so that we can take a single-phase alternating current, and convert it into polyphase of any desired number.

I have chosen for my work, the conversion of single phase to

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three-phase, because the three-phase motors which we have been able to construct, give us very much less trouble than the two-phase. In a series of experiments, I have found that the two-phase motor would run at a number of speeds, especially when supplied with current from a phasing transformer. I supposed the trouble arose from harmonics, but of this I am not certain. The triphase motor never has given us any of this trouble. These experiments, however, were carried out before the transformers had been refined; and, now that we are getting more perfect results, I think it is very probable that we could return to the two-phase motor and get much better results than when first tried. The following is a description of an arrangement of condensers and cores to produce polyphase and single-phase alternating cur-

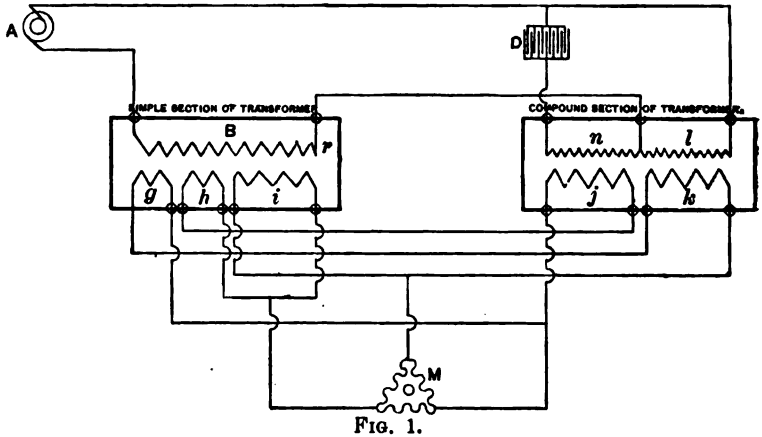

FIG. 1.

rents. Many different arrangements of condensers and inductances have been tried, and all have failed to keep their phases at a working relation, except the one I am about to describe.

A diagram of the phasing transformer and connections with the generator and motor, will be found in Fig. 1, A being the generator, B the simple section of the transformer, D the condenser, and M the motor; r, primary of the simple section of the transformer, n and l, primary of the compound section; g, h, and i, secondaries of the simple section of the transformer, and j and k secondaries of the compound section. The primary of the simple section of the transformer is in series with the compound section, and condenser. By the proper adjustment of capacity and inductance, the magnetic flux in the core of the compound

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section is approximately 90 degrees in phase behind the simple section, then, in order to get three phases from the two, I resort to resultants in the secondaries: *g* and *k* constitute one phase, *h* and *j* a second, and *i* the third. The essence of this invention rests in the arrangement of the compound section of the transformer and condenser. There are, undoubtedly, several ways of explaining the theories involved in this device, and most people would prefer the mathematical description, but, as I did not hit upon the invention by that method, I shall follow in the explanation, the same method of reasoning as I used to arrive at the result. In order to explain the theory involved in this, refer to Fig. 2, in which A is the generator, E, the inductance, D, a condenser or capacity, *l* and *n* represent the leads to the inductance E, and

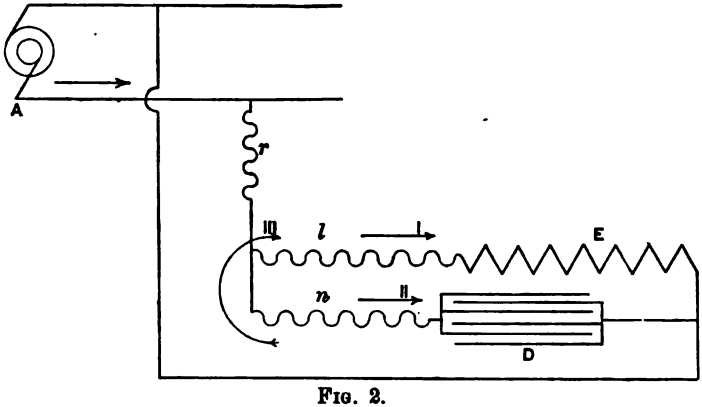

FIG. 2.

to the capacity D. If the generator is generating an electromotive force in the direction of the arrow, Fig. 2, a current will flow through the lead *l* and the inductance E, as represented by the arrow prime, and through *n* into D, in the direction of the arrow second, as indicated by the curves in Fig. 3; that is, during the rise of the electromotive force through the machine from the point, *o*, to the top of the wave at *p*, the current will flow in parallel into or through the inductance E, and the capacity D, Fig. 2. As soon as the wave of the electromotive force commences to decline from the point *p*, the condenser will begin to discharge, and the current flowing from it will be in the direction of the arrow third, Fig. 2. Also, at the same time, the inductance will discharge its energy by a current in the direction of

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arrow third, so that the current represented by arrow third will cross the zero line at point *t*, Fig 3., or is delayed by a time equal to 90 degrees. Thus, we see that the current represented by arrow third will be lagging in its time period considerably behind that in the lead *r*, represented by curve *o–p*. Now, if we wind the lead *l* and the lead *n*, upon an iron core as shown in Fig. 4, in opposite directions and of the same number of turns, and have the inductance E bear a proper relation to the capacity D, so that the currents represented by arrow prime and arrow second shall be equal, no magnetic flux will be produced in the core during the rise of the potential of the machine from *o* to *p* on the curve, but during the fall of the electromotive force of the machine, and during the discharge of the inductance and condenser which is rep-

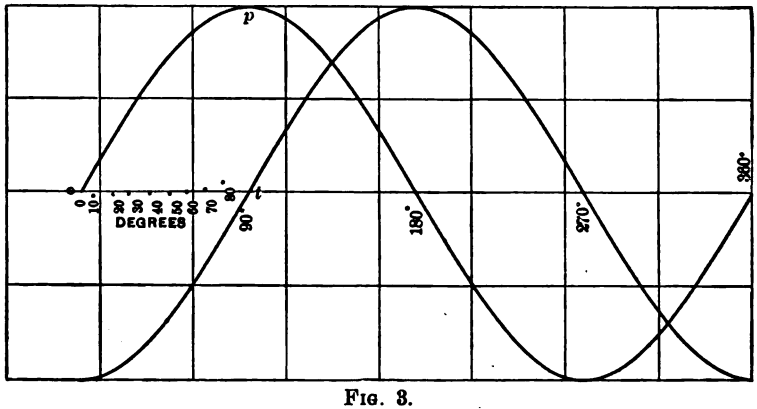

FIG. 3.

resented by arrow third, Fig. 2, the currents flowing through *n* and *l* will be in series and flowing in the same direction; consequently, the magnetic flux will be approximately 90 degrees later than it would be if charged directly from the machine. I have represented in Fig. 2, a section of lead by *r*, and it will now be clearly seen that the current in the lead *r*, will have a phase difference from the combined or resultant phases in the leads *l* and *n*. Furthermore, a current in the lead *r* will be in lead of the electromotive force of the machine, because the inductance and the condenser, previously described, cut off the flow of the current before the machine has reached the zero point, and when the lead *r* is placed upon an iron core as shown in Fig. 4, it has a tendency to lag, which counter-balances the lead and leaves the main line

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current somewhere near in phase with the E. M. F. of the generator.

Please refer now to Fig. 4, where the leads l and n are wound in opposite directions, and completely interlaced upon the iron core L; the generator, inductance and capacity being indicated by the same symbols as in previous figures. The lead r is here wound upon the second iron core, which constitutes the primary of the simple section of the transformer as shown at B, Fig. 1. In reducing to practice and applying the transformer to an induction motor, we find that the inductance E, can be dispensed with, as the apparent inductance produced by the motor furnishes all the lag necessary; and, it will be noted, that in Fig. 1, the extra inductance which we used in our first experiments, is left out of the combination. The lead from the simple section of the trans-

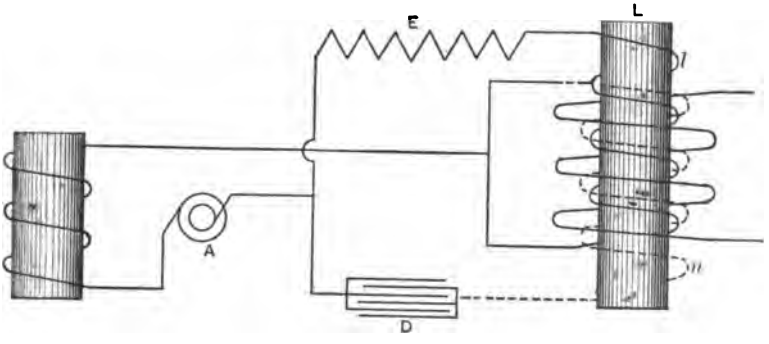

FIG. 4.

former, it will be noted, goes to the center of the compound section. This diagram does not represent the true condition of the compound section, for the winding n and l are together, or, as before mentioned, interlaced upon the core. The magnetic flux in the two sections of the transformer are approximately 90 degrees apart. The secondaries are therefore wound each partially upon the two cores, so that the three resultant phases may be produced from two, this being in accordance with Mr. Fred. S. Hunting's invention for changing two phases to three. For the description of this I will quote Mr. Hunting's own words, and the plan is in Fig. 5.

"If P^1 and P^2 represent two primary circuits supplied respec-
"tively with alternating currents differing in phase, or disposed
"in any other suitable manner so that the fluctuating magnetic

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"impulses developed in the cores M^1 and M^2 differ in time, then "the secondary currents developed in circuits s^1 and s^2, will differ "in time period. If other circuits as s^3 and s^4, be so arranged "that part of their convolutions will enclose one magnetic core "and part another, there will be developed in these circuits a "resultant current due to the combined action of both magnetic "cores, and this current may be given any desired degree of phase "displacement with reference to the current in primary coils P_1 "and P^2, accordingly as the number of convolutions surrounding "the respective cores is varied. For example, if, as shown in "circuit s^4 an equal number of convolutions is placed around each "core, then there will be developed in circuit s^4 a resultant cur-"rent having its phase half way between the phase of current in

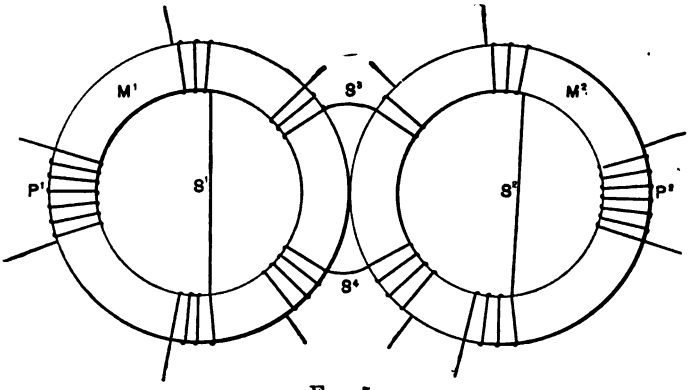

FIG. 5.

"coils P^1 and P^2. If the number of convolutions on the two cores "vary in the proportion of three to two, and be joined together "as indicated by the coils s^3, the resulting current produced by "these coils will be closer in phase to the current flowing in P^1, "providing the larger number of convolutions be placed as indi-"cated in the diagram upon the magnetic core controlled by coil "P^1. Thus, by varying the relative proportions of the two coils "inclosing the two magnetic circuits, a resulting current of any "desired phase displacement with reference to the phase of coils "P^1 and P^2 may be developed. It will thus be seen that by means "of two magnetic circuits or cores in which magneto-motive "forces differing in phase are developed, we may produce any "desired number of currents of differing phase, and may produce

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"a definite degree of phase displacement, and the resultant cur-
"rent may in any case be shifted closer to the phase of magneto-
"motive force in either core, by increasing the inductive influence
"of said core upon the circuit carrying the resultant current.

"In the organization shown in the diagram, we will have four
"secondary currents developed from the primary coils P^1 and P^2,
"and assuming that the currents flowing through these coils
"differ in phase, all of said secondary currents will differ in
"phase."

Mr. Scott's invention for changing two phases to three, may also be used, and is shown in Fig. 6. Making the resultants in this manner by means of the secondary windings, contributes also

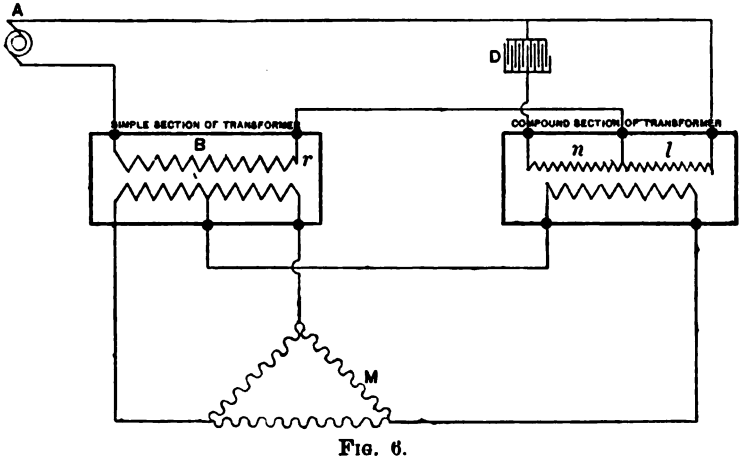

FIG. 6.

to steadiness of phasing. If desired, two secondaries having a proper two-phase relation may be used on the motor.

The experimental work in which I have been greatly assisted by Messrs. Hulse and Chapman, has occupied a long time and has passed through a great many stages. The results represent a great deal of patience, and we have chased the phases from zero to 180 degrees, back and forth, until there is a well-worn path between these two points, but finally we have a set of beautiful results, and the electromotive force curves will be found in Fig. 7, taken from the transformer, in connection with a half-horse power motor, running at full load, and Fig. 8 gives the current curves of the same. This motor gives powerful starting torque, and it gives me pleasure to show it to you here in operation. I want to

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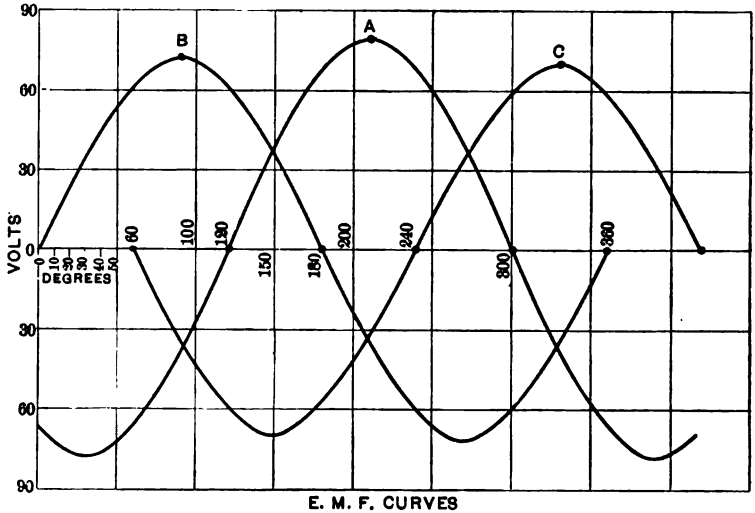
bring to your attention one feature of the compound coil used in combination with the condenser, which will be found in Figs. 9 and 10. If we suppose a direction of motion as shown by the arrow, and the current in the condenser branch leads by 90 degrees, which is represented at *b*, and the current in the inductance branch lags by 90 degrees as indicated at *c*, and the wires carrying these currents are wound in opposite directions upon the core, we will have a resultant current, which is represented by extension *d*. Increase of load, changes the phase relation of the individual branches, but not the resultant secondary, and this is explained by reference to Fig. 10, where a 75 degree lead, and a



E. M. F. CURVES

FIG. 7.

75 degree lag are represented by the respective branches, and as the branches are wound in opposite directions, we find that when *b* is turned over, it becomes a lag of 105 degrees, and the resultant of 75 degrees and 105 degrees again produce 90 degrees lag, and the value again represented by the extension *d*, the value of the current is slightly less, but its resultant phase is the same as is represented in Fig. 9. This explains the steadiness of phasing, which we are able to obtain. This may be explained by another method of diagramming as is shown in Figs. 11 and 12, where curve *a* represents the fundamental current, curve *b*, Fig. 11, a lead of 90 degrees, curve *c* a lag of 90 degrees, and then *b*

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being turned over, unites with *c* to produce the resultant *d*, which is 90 degrees in lag of fundamental curve *a*. Now, in referring to Fig. 12, where the fundamental current is again represented by *a*; curve *b* represents a lead of 75 degrees, and full line curve *c* represents a lag of 75 degrees; then, when curve *b* is turned over in the windings, as shown in the dotted line, the coils being wound upon the same core, a resultant effect is represented by the curve *d*, which is 90 degrees in phase from fundamental curve *a*. Thus we see by increase of load, which tends to decrease the lead

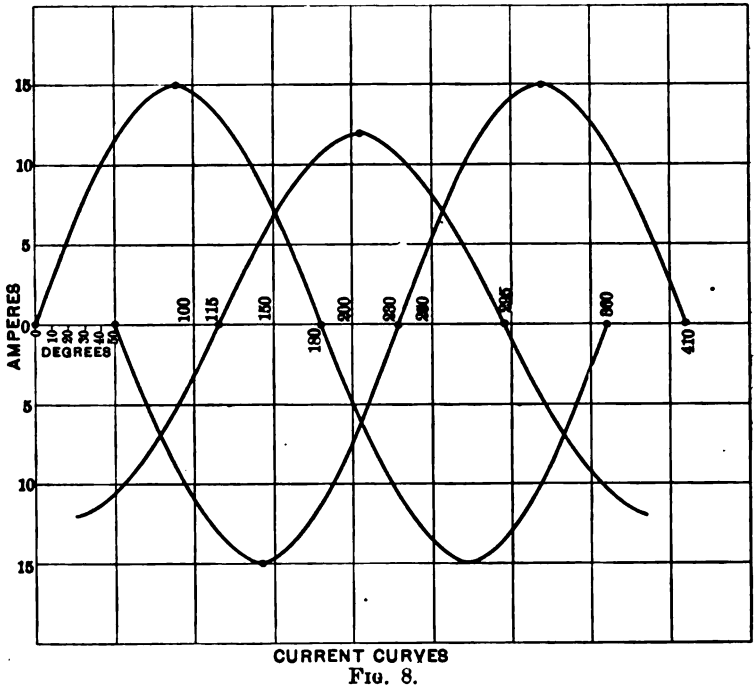

FIG. 8.

of the condenser circuit, and also decreases the lag of inductance circuit, our resultant is still in the same phase relation to the fundamental current.

The power factor is found to be very good. The current in the main line, feeding the transformer varying from 10 degrees lead at full load, to 35 degrees lag at no load, and the motor at starting produces the same effect as when working at full load, so that we have very good phasing for starting and full load, as well as a good power factor, it being 82 per cent. even at light loads,

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and the probability is that we will have very much better results upon larger sized transformers.

The condenser in this combination fills two very important functions, first assists in the phasing, and second prevents the

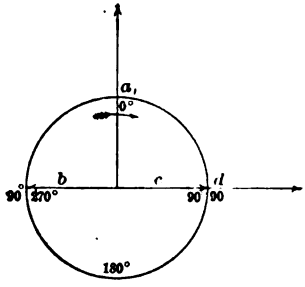

FIG. 9.

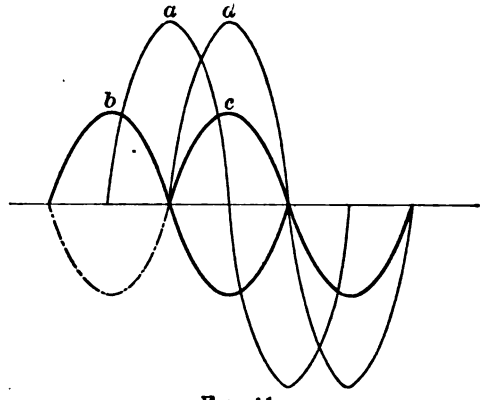

FIG. 11.

lag upon the line. This arrangement does not prevent the idle currents flowing in the motor circuits, and the secondaries of the phasing transformer, and we find in small motors with the high period of 140 cycles that the apparent energy in the motor circuits is sometimes two and one-half times the apparent energy in

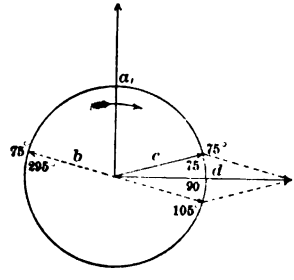

FIG. 10.

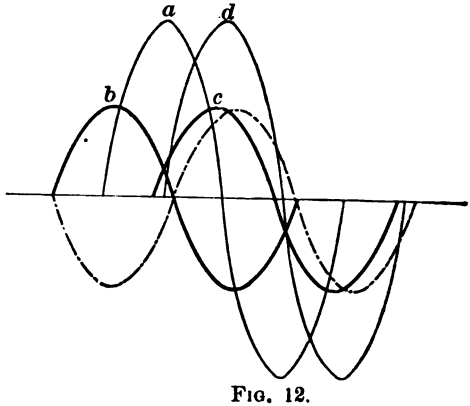

FIG. 12.

the main line. The capacity of condenser for a one-half horse-power motor when 1,000 volts are supplied to the transformer is about 2.4 microfarads. Our condenser for this size, without connections, occupies a space of a cube four inches on each side, and

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capable of enduring 3,000 volts, or a factor of safety of four, as the voltage on the condenser is about 700. Of course, it will be understood by those familiar with the designs of induction motors, that it is impossible to design a small motor with small power factor, as the air-gap necessary for mechanical construction has to be so large in proportion to the size of the motor.

Many attempts have been made by placing the condenser in direct connection with motors to produce rotary fields, but have so far been attended with little success; as the trade requires the motor to be of comparatively low voltage, which calls for a large capacity in the condenser, and as the output of the condenser of a given capacity is proportional to the square of the voltage, it will be seen how advantageous it is to place the condenser in combination with the primary of the step-down transformer.

It may seem trite to call your attention to the fact that the transformer reduces the voltage at the same time it does the phasing, but I think it is so important that I wish particularly to emphasize the fact. It is also of great importance that the device has no moving parts.

Upon reference to the cuts showing the curves obtained of the electromotive force and current, it will be readily seen that they are all of true sine form. The current for this work was obtained from a 75 K. W. Slattery alternating machine. This machine has a surface winding on the armature, and, therefore, gives practically a sine wave. Just what the transformer may do on all the various dynamos that are in the market, giving all sorts of complex waves, it is difficult to say, with our present experience, but, so far as we know now, the transformer tends to smooth out all the irregularities.

While the principal use for this device at present seems to be the application of polyphase motors to single-phase lighting systems, many new ones, undoubtedly, will be found. It may seem bold to think of applying this to long-distance trolley railroads, but I am hoping to have it done.

It is much more simple to have one trolley wire with track return, than to have two trolley wires which would be required by the direct application of polyphase systems. A large amount of power requires either a large current or high voltage, in order that the resistance of contact of whatever device is used to make connection to line need not be too great. As viewed at present, it seems as if the alternating current must be used for this work.

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If so, and unless the traffic is extremely frequent, it will take many more transformers, if they be placed along the line, than if the transformation is made upon the car or locomotive; because the transformers along the line having no trains or cars near them, would be idle.

If the voltage is stepped down on the car or locomotive, it is just as economical to do it by the phasing transformer, with the exception of the added weight of condensers, which for a 1,200 H. P. locomotive will be about two tons, and this is not of consequence on so large a power.

These condensers are very compact and efficient, and will stand from three to four times their working voltage, without puncturing the dielectric. I am sorry I cannot show you the condenser in all its details, but for certain reasons I cannot do so at present, but will present it to the INSTITUTE at the first opportunity.

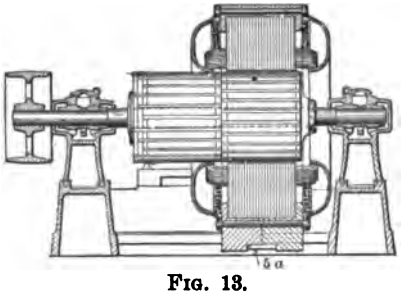

FIG. 13.

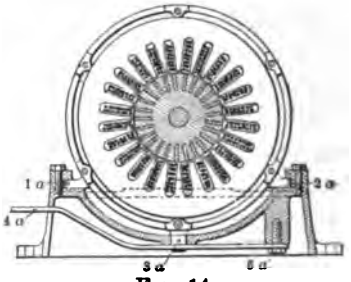

FIG. 14.

A brief description of the motor may be in order, although it does not belong strictly to this subject. We met with much difficulty in developing a motor for so high a periodicity as 140 cycles. It is necessary to keep the density so low, and it is always such a temptation to try to get all the power from a given piece of apparatus, that they are always heating much more than they should.

With a large number of poles and slots, we found that any use of wide bars in the armature was out of the question, for the eddying currents in the copper were too serious. *We also looked for difficulties which we never found.* At times we thought the heating was due to higher harmonics produced from the phasing transformer; but the fact is, we never found any, unless it was in the experiments upon the two-phase motor. As mentioned before, the waves are all of the true sine form.

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Cuts of the motor are shown in Figs. 13 and 14, the rotary field being the exterior or stationary part, and the secondary or induced constituting the armature. The armature is composed of two sections, or practically two armatures end to end upon the same shaft, one of the armatures having a low resistance winding and the other a comparatively high resistance; the field is placed over a high resistance for starting, and shifted by means of a lever over the low resistance, when it has nearly attained speed. Of course, this arrangement is for securing the starting up of the motor, and has nothing to do with the phasing transformer, and the motor might have rings for connecting the starting resistance to the armature and operate quite as well. The sliding of the field gave trouble, as the air-gap has to be small, and the play at the sides (noted 1*a* and 2*a*) allowed the armature to strike against the field, and when a tight fit was made, which would work easily when cold, it would stick fast when the motor rose in temperature; the writer therefore decided to give it quite a clearance at these points, and give it a guide at the bottom of the field shown at 3*a*. This being central and comparatively thin, the expansion is not sufficient to cause sticking, also the guides at 1*a* and 2*a*, being thin vertically, they may fit close and still slide easily. The lever for moving crown back and forth is shown at 4*a* Fig. 14, and 5*a* Fig. 13. It fits loosely, having a fulcrum at 6*a*.

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Discussion.

Dr. Charles E. Emery:—Mr. Chairman, I am very much pleased with the paper and the results here stated. We congratulate Mr. Bradley on the success that has been attained by his efforts, and wish that it may be continued. The details need considerable study, and are perhaps not brought out in detail sufficiently to secure an extended discussion at the present time. I rise, however, to express my appreciation of the work.

Mr. Nelson W. Perry:—I would like to ask Mr. Bradley whether my understanding of this paper is correct—that he will take the ordinary single-phase current and convert that into a multiphase current or polyphase current, and if so, whether it is necessary that there should be a specially designed motor to work with the polyphase current; whether his intention is not to take any single-phase current and to convert it into a polyphase current, so that it would operate any make of polyphase motor.

Mr. Bradley:—We have not, so far, made any effort to adapt it for every polyphase motor, but if a standard voltage is adopted every motor of standard make can be used. This motor here is about 75 volts.

The President:—If your load changes, do not your phases change? For instance, you have a single-phase current changed into a two-phase, or three-phase current, whichever you want to change it to; now, if your load changes, do not the relative phases of the components?

Mr. Bradley:—Yes. But it is so planned that the phases are exactly right for full load. A starting torque is always full load. The phases tend toward single-phase at light loads. But the single-phase is sufficient to run the light load.

The President:—Yes, I see what you mean. But I think your efficiency would be exceedingly small.

Mr. Bradley:—No.

The President:—All right.

Mr. Bradley:—Well then, a single-phase motor would be of low efficiency.

The President:—Nobody ever denies that at a light load it is low.

Mr. Bradley:—At a low rate. That is a low rate before it has attained a speed. But in attaining speed and accelerating, your phases come right, because you have the full torque.

The President:—I was speaking of traction work. Is it possible to take your one phase and change that in the car to two or three phase, and get them in such shape that you may start up at any efficiency whatever.

Mr. Bradley:—Yes. It takes full torque at starting.

The President:—Full torque just as if you put in resistance.

Mr. Bradley:—Yes; of course it needs resistance in the secondary.

The President:—I see.

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MR. BRADLEY:—It needs resistance in the secondary in order to keep the torque. But as long as the resistance is varied in proportion to the speed, why the inductance remains the same, and therefore it maintains the same relation.

MR. JOSEPH SACHS:—I would like to ask Mr. Bradley whether the essential difference in diagram Fig. 1 and diagram Fig. 6 is not entirely in the secondary connections.

MR. BRADLEY:—Yes.

MR. SACHS:—And I also understand that Fig. 6 is the Scott method.

MR. BRADLEY:—Yes Mr President, I will start up the motor and perhaps that will stir up discussion. (Mr. Bradley started the motor). We expected to have had means of showing the torque of the motor but we were defeated in that at the last minute.

MR. SACHS:—Is not that the same motor that you showed at the New York Electrical Society several months ago?

MR. BRADLEY:—The same in principle.

MR. SACHS:—More perfect I suppose.

MR. BRADLEY:—This is 140 cycles. That was 60. The 140 cycle motor is a great deal more difficult.

MR. SACHS:—The principles of construction are exactly the same though, aren't they?

MR. BRADLEY:—Yes.

DR. EMERY:—What is the speed?

MR. BRADLEY:—About 2,000.

DR. W. E. GEYER:—I am sorry to say I have not had time to look at this paper. It is evidently very interesting. I think I understood Mr. Bradley to say that these curves that he put down were all true sine curves. Perhaps he has an extra ready way of determining the shape of those curves, and if he has, I think it would be interesting if he would tell us what it is.

MR. BRADLEY:—We do it by the contact method. It is known to almost all the scientific people. There is a telephone and an arrangement of resistance balanced against—do you want a full description of it?

PROF. GEYER:—No. I thought perhaps you had something extra about it.

MR. BRADLEY:—No. But perhaps I had better describe it, as there may be some present who are not familiar with it. There is a disk on the generator that has a very small contact made of thin copper or steel. We are using copper. We have a hard rubber disk with a saw cut across the surface, and use a watch spring for the brush to make the contact, with a lever to change the position of the brush, and a scale laid off in degrees over which a pointer from the lever moves. One of the terminals that comes from the contact is carried to one end of the resistance. The other contact is movable along the resistance. Then we

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take the battery or a direct current from another dynamo and connect with the movable terminal, and with the voltmeter also across that in shunt, and a telephone that is connected in the line leading to the resistance. The contact along the resistance is moved until the telephone is silent, when it shows that the E. M. F. of the machine is balanced against the direct E. M. F. force; and then the voltage is read off on the voltmeter showing the voltage at the moment the contact is made. Now if the contact lever is moved to a zero position of the generator where the wave crosses the neutral line, and the contact is moved until the telephone is silent, the reading then is "no voltage." Then by moving the lever degree by degree, and moving the contact until the telephone is silent each time and reading off, it shows the voltage at each point on the passing of the contact piece in the disk under the brush. In that way we get a complete plotting of the curve of the machine.

Now, if instead of making our connections with the machine, we make our connections at some other point in the system—the motor and transformer or whatever you like, connected with the machine, of course the time period being supplied by the machine, it must therefore rotate in synchronism and read off the E. M. F. and shape of the wave in any of the circuits, between these two in the outside pair, the transformer or any other part of any apparatus that may be in the system connected to that particular machine. We have used it a great deal and found it very successful. The currents are read off in very much the same way, except that we use a resistance in series with the work, and take the drop over the resistance by the same method. This, with small currents, is difficult, but we get sufficient to give us the plotting of the curve. We have not had machines large enough to give a current great enough so that we could get perfectly accurate results as to the current, but accurately enough to show that it is a sine wave.

Mr. A. E. Kennelly:—I cannot say that I have had any experience on this subject as I have had the pleasure of seeing this motor for the first time to-night. But I would like to make a sketch to see if my idea of its operation is a correct one. As I understand it, there are two transformers, one of which is an ordinary transformer and the other of which is a transformer divided in two halves. Now this first transformer produces E. M. F. in the secondary. It may be represented, say, by a straight line, six inches long and horizontal. The second transformer, inasmuch as it contains a condenser and a suitable inductance in circuit with it, produces at full load an E. M. F. which is at right angles to the first. Now those two E. M. F.'s are capable, when united properly in their secondary circuits, of operating a two-phase motor. But the object of the designer in this case was to operate a three-phase motor, and to do that he

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arranged it in this way. What is needed in a three-phase motor are three E. M. F.'s at angles of 120° apart like that (illustrating). He takes for the first E. M. F. a portion of this single phase E. M. F. Then he divides the remainder of that up into two smaller, and he cuts the vertical one in half and unites a little piece of each horizontal with the vertical in this way, a short piece of the horizontal, then half the vertical, giving a resultant in that direction, 120° off here, so; and then the remainder of the horizontal he combines with this backwards, producing that combination and therefore 120° off here. The three E. M. F.'s at full load are then capable of supplying the triphase system of currents that is needed in the motor. But at light load this combination which gives the E. M. F. at right angles to the ordinary single phase transformer is no longer able to sustain its full value, and these two diminish very much. So that finally you get a close approach to a single phase E. M. F. and a single phase motor. Only at full load currents can you get the triphase combination. Am I right?

MR. BRADLEY:—That is correct. I would like to say that that is all that is necessary.

MR. KENNELLY:—I might say it is not only necessary but important.

DR. CARY T. HUTCHINSON:—It does not seem to me that Mr. Bradley has explained at all why his arrangement in Fig. 6 differs from the arrangement shown in Fig. 1. Why does he split the secondary up into three parts instead of two, and in the other case into two parts instead of one. The primaries are identical. Where does the difference in effect come in? What is the difference in the results?

MR. BRADLEY:—The results are not different. Mr. Scott's plan would require a little less wire, a little less copper, but only a little less.

DR. HUTCHINSON:—Mr. Scott's method does all that Mr. Bradley's does, and it is simple.

MR. BRADLEY:—Yes, it is a little simpler; that is so far as that particular part of it goes.

DR. HUTCHINSON:—Well, what other part of it is there? That is what I asked you. Is there any other part?

MR. BRADLEY:—There is decidedly another part.

DR. HUTCHINSON:—What is it then?

MR. BRADLEY:—I described that in what I styled the combined section of the transformer. The combined section of the transformer gives me a method of phasing. Those are wound interlaced, which gives the two-phase. By running a two-phase motor I would not need to use either Mr. Scott's plan or Mr. Hunting's plan. But in order to convert into three I must use one plan or the other. There is very little difference between the two. Mr. Scott's is a little more simple and requires a little less wire. The invention lies in the primary, not in the secondary. I thought the description was very full as regards that.

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DR. HUTCHINSON:—In your diagram the primary is identical with the other diagram.

MR. BRADLEY:—The diagram in Fig. 4?

DR. HUTCHINSON:—Fig. 6 and Fig. 1.

MR BRADLEY:—The essence of the invention lies in getting M. M. F.'s in two cores differing in phase. This is done by means of the condenser and inductance and their connecting circuits, which are wound in opposite directions to produce a resultant in one core, while the other core is enclosed by the convolutions of the line leading to the above core vibration, which produces two phases as shown in Fig. 4. Then having the two phases I use these other gentlemen's inventions to convert it from two-phase into three.

MR. F. N. WATERMAN:—I would like to ask one question, if I may, and that is whether these two curves shown in Fig. 7, which show exact three-phase relations, could be obtained equally well from the motor at the period of starting. I understand that this is taken from a half-horse-power motor running at full load. What would the phase differences be at the moment of starting.

MR. BRADLEY:—They are the same.

MR. WATERMAN:—They are the same as at full load?

MR. BRADLEY:—Yes.

MR. WATERMAN:—May I ask a question further, and that is, what the departure might be expected to be in a motor, say of the same size, while running at 10 per cent. of its load.

MR. BRADLEY:—Running at 10 per cent. of its load the phases would be quite different. It would approach a single phase condition.

MR. WATERMAN:—I understood. I merely wanted to know if you could tell us about how near that was.

MR. BRADLEY:—Well, I have no exact data to give you now on that question. Perhaps you do not realize that in starting up, the motor really exerts full torque and therefore the inductance is the same as when running at full load. In such a case as this, where there are two sets of resistances in the armature part, the resistances have to be planned, so that it shall have the same inductance in starting as at full running load.

MR. WATERMAN:—That is the point I had in mind. It is evident that these conditions represented in Fig. 7 are not obtained when you use the other side of the armature, and my point was whether in the condition in which you have it for starting, the three-phase condition is attained with anything like the perfection shown in the diagram.

MR. BRADLEY:—Yes, it is, and that is done by the resistance in the secondary; while accelerating, it is exerting full torque, and the inductance is approximately the same as at full running load. Of course it may be that with that particular armature we have not arrived at exactly the right proportions, but we came near enough so that we have a good starting torque.

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DR. HUTCHINSON:—Do you purpose with a large motor to have a double armature, and to slide it along from one side to another?

MR. BRADLEY:—Not necessarily.

DR. HUTCHINSON:—This is a double armature practically.

MR. BRADLEY:—This paper is on the subject of the transformer, and the motor is the most convenient one I had at hand to demonstrate with.

DR. HUTCHINSON:—A thing of that kind is absolutely unpracticable for a large machine.

MR. BRADLEY:—Well, I don't know about that.

DR. HUTCHINSON:—I think nearly everybody would agree with me on that point. Why use a double armature when you can do the same thing by having resistance?

MR. BRADLEY:—Of course it is an engineering question that anybody can take up for himself.

DR. HUTCHINSON:—I think anybody will take it against a double armature.

MR. BRADLEY:—That may be. We have had a great many discussions over that subject, and you may be right.

DR. HUTCHINSON:—So may you.

[Adjourned.]

DISCUSSION IN CHICAGO.

PROF. W. M. STINE:—The final decision on such a plan as is here proposed must rest on its commercial value. To some extent such a power system must come in direct competition with the simple motors for continuous current service. The first cost of the polyphase equipment must be relatively high, and its working efficiency must prove somewhat lower than direct current transmission. But this apparatus has another field of application peculiarly its own, to afford a paying day load for the alternating current lighting stations. Judging from what we have seen, it seems reasonable to suppose that the first cost can be brought within such figures as, taking its adaptability and the day load feature into account, would be low enough to enable it to be generally introduced. Mr. Bradley has certainly offered a satisfactory solution of the power problem for single-phase transmission. The problem has been worked out by Professor Rowland, but his solution does not readily lend itself to a commercial form. Others have attempted somewhat similar designs, but have failed because unable to construct a satisfactory condenser. Mr. Bradley seems confident that he has overcome the difficulty and can construct condensers which will prove commercially reliable with high voltage.

This apparatus contains some elements which should make it serviceable for long-distance railway work. From the present outlook, the alternating current is the only mode of electrical power transmission suitable for the work. This would ordinarily

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necessitate large transformers placed at frequent intervals. In order to meet the demands of a mixed freight and passenger service, such power transformers would have to be of very great capacity. They could only be used intermittently with the fluctuations of daily traffic, and during most of the time must represent idle capital. The open circuit losses in such transformers taken for the entire system would be a heavy operating expense. Should Mr. Bradley's scheme prove feasible for railway work, these losses would be avoided, for each train would carry its own transformer, from which the idle current could be cut off when not in use. This would result in strengthening the power sections so as to include possibly an entire division served from one central power plant, and, as a consequence, the train load would be practically constant over the day.

DIED.

CURTISS :—At Boston, Mass , October 10th, 1895, George Franklin Curtiss, Electrical Engineer with the General Electric Company, at Schenectady, N. Y. Mr. Curtiss was born at Derby, Conn., September 2d, 1861. He took a four years' course in electrical engineering at the Massachusetts Institute of Technology, class of '87. He subsequently devoted three years to experimental work in the laboratories of the Thomson-Houston Electric Company, at Lynn, and continued in the service of that company and the General Electric Company until his death. Mr. Curtiss was elected an associate member of the INSTITUTE April 2d, 1889, and transferred to membership Nov. 24th, 1891.

POPE :—At Great Barrington, Mass., October 13th, 1895, Franklin Leonard Pope, formerly of New York City, and Elizabeth, N. J. Mr. Pope was born in Great Barrington, December 2d, 1840. He entered the service of the American Telegraph Company in that town in 1858. His subsequent life was devoted to the study and practice of electrical science. He was a charter member of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, and one of its first vice-presidents, serving from 1884 to 1886, and was elected president in 1886 ; upon the expiration of his term in 1887, he was again elected vice-president for the term ending in 1889.

CUSHMAN :—At his home, 337 West 22d St., New York City, October 24th, 1895, Holbrook Cushman, Head Instructor Department of Physics, Columbia College. Mr. Cushman was 38 years of age, and graduated from Columbia, class of '78. He was appointed fellow in science, and continued his studies at Würzburg, Germany. After returning to this country he engaged in electrical practice with the Western Union Telegraph Company and the Western Electric Company. In 1890 he received the appointment from Columbia College which he held up to his death, which was due to heart disease. Mr. Cushman was elected an associate member of the INSTITUTE June 2d, 1888.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, October 23rd, 1895.

The 100th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by Vice-President Francis B. Crocker, at 8 P. M.

THE CHAIRMAN:—[Vice-President Crocker.] Gentlemen, the Secretary has certain announcements to make in regard to routine matters.

THE SECRETARY:—At the meeting of the Council held at the office of the INSTITUTE this afternoon, the following associate members were elected:

Name.	Address.	Endorsed by
BYRNE, HARRY	Organizer, The National School of Electricity, Chicago, Ill.; residence, 5620 Drexel Ave.	C. C. Haskins. Harry H. Hornsby. Arthur Frantzen.
COLES, EDMUND P.	Special Tester, General Electric Co., Schenectady, N.Y.; residence, 240 Union St.	John B. Blood. Thorburn Reid. W. J. Davis, Jr.
COLLES, GEORGE W., JR.,	Draughtsman, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	Wm. E. Geyer. Henry Morton. Henry Floy.
CRAWFORD, L. G.	Sup't, Repair Dep't Gen'l Electric Co., Chicago, Ill.	Frank H. Dorr. Clare F. Beames. Chas. P. Steinmetz.
SHONNARD, HAROLD W.	Designer and Foreman, The Electric Self-Playing Piano Co, 333 W. 36th St., New York City; residence, 23 W. 43 St., Bayonne, N. J.	T. D. Bunce. Frank Martin. Robt. Lundell.
WALKER, ARTHUR F.	Sup't and Electrical Engineer, Edison Light Co., Grand Rapids, Mich.	Frank B. Rae. Chas. Wirt. W. S. Barstow.

Total, 6.

THE CHAIRMAN:—I have to announce officially, what you all know personally, the fact that one of our most distinguished members and past officers was accidentally killed by the agency

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which he was most familiar with, and that owing to the unavoidable absence of Dr. Duncan, who has interested himself in this matter, I am called upon to take the Chair. Dr. Duncan has very appropriately selected Mr. Thomas D. Lockwood to prepare and to present to you suitable resolutions in regard to the death of Franklin Leonard Pope, Past-President of the INSTITUTE. I will now call upon Mr. Lockwood to present these resolutions.

MR. LOCKWOOD:—Mr. Chairman: It seems to me exceedingly fitting that before proceeding with the regular order of business, the INSTITUTE, as a body, should recognize that its duty, albeit a melancholy one, is to consider the sad event you have announced, and to pay its sorrowful but sincere tribute of honor and affection to the memory of our lamented Past-President and distinguished fellow member, Franklin Leonard Pope.

We must all deplore very much that thus early in the season of 1895 and 1896, we are under the painful necessity of recording the loss of one whom we have known and respected for so long—and yet, alas, for so short a time. I have been honored with Mr. Pope's friendship for some twenty years, and for ten years before the beginning of that period, I knew of his name, reputation and abilities, and I had set before myself, his example, as one well worthy of emulation in the career I hope to achieve.

It does not appear to me that this is the proper time to recount biographically, his life-story and work, since I am well assured that that will be done for the archives of this INSTITUTE by hands more skilful, and by tongues more eloquent than mine; but I cannot refrain from briefly testifying for myself, as a private citizen, a brother in profession and a fellow member and associate in this INSTITUTE, to the high sentiments of regard and admiration which from the earliest moment of our several years of acquaintance I have entertained and cherished for Mr. Pope, and the heavy and crushing sense of personal loss which has weighed upon me since I first read the sad news. And yet, Mr. Chairman and gentlemen, I welcome the intensity of the personal loss of which I have spoken, because I feel and I am convinced, that by it I am enabled in some measure the more truly to sympathize with the incomparably deeper sorrow of his family and kindred.

The life of Franklin L. Pope, as we all know, was an essentially busy one. It was one of constant and unremitting toil. When I first heard of him I was but a boy and he was comparatively a young man; but even then he was in the forefront of the work, and he was chief of exploration for the Russian-American Telegraph, which the Western Union Telegraph Company at that time had in process of construction, under the belief that the transatlantic cable could never be successfully laid. His toil, however, differed from that of the majority of mankind, in that it was three-fold, for not only did he toil to acquire and accumulate knowledge, but he also toiled in the utilization of

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knowledge, and furthermore, and I think this was better than all, he always toiled with the glad hope of imparting knowledge, and in all of these three varying methods he toiled to the end, and we can truly say, he veritably "died in the harness." We may well sorrow as a body that he was not spared to work longer or to more fully enjoy the fruitage and harvest of the seeds which he has ever labored to sow, and the young growth of which he ever labored to prosper.

Those of us who had the happiness of a close intimacy with Mr. Pope will bear me out when I say that we shall remember him always as showing the kindness and genial spirit of a true friend; as being one who reverenced the right; endeavoring always to do his duty as he saw it; and as possessing, in addition to marvelous ability in many directions, and great powers of generalization, analysis and expression, a large share of modesty, that inherent attribute of true genius and talent. Employing the words of the inspired writer, we then may truly say that "a prince and a great man" has been taken from us, and I am confident that every member of this INSTITUTE will regard it as a privilege to be associated with the expression of our sorrow and our sympathy with the bereaved family. With this confidence, Mr. Chairman, I have therefore a sad satisfaction in presenting resolutions which formulate such expression, and in moving their adoption by the INSTITUTE.

These resolutions are as follows:

Whereas, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has heard with heartfelt sorrow of the sudden death by a lamentable accident, of its Past-President, Franklin Leonard Pope; and

Whereas, we, the members, Council and officers of the INSTITUTE desire to express our profound realization of the bereavment we have sustained, and the sincere grief we experience, and to record in fitting terms our keen appreciation of the great worth and high qualities of our fellow member; his eminent services to our organization; and his able, unwearying and successful work in applying electrical energy to many useful purposes; it is therefore

Resolved, that by the death of Mr. Pope, called away in the full fruition of manhood and the meridian vigor of intellect, the profession at large has suffered an incalculable loss, and the INSTITUTE has been deprived of a most distinguished and valued member, and a wise and sagacious counsellor, endeared to many members by long, pleasant and affectionate intercourse, and esteemed and respected by all, no less for his kindly and warm-hearted nature and dignified simplicity of character, than for his universally acknowledged genius and great ability.

Resolved, that we hereby express the poignant grief wherewith we contemplate the sad event which has taken from us one who, whether in the earliest days of our association, co-operating in its successful establishment, urbanely and efficiently presiding as our chief Executive Officer at business and social meetings, discreetly and judiciously performing the unassuming duties of a member of the Committee of Editing, or in the capacity of an individual member serving the interests of harmony and stability, has uniformly had the dignity of

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the INSTITUTE at heart, and has assiduously, cheerfully, and faithfully labored for its welfare; and while we sincerely mourn the loss of an associate so eminent and useful, thus suddenly withdrawn from the activities of this present life, we more earnestly grieve for the parting from a friend so sincere, faithful and true.

Resolved, that we extend to his stricken family our tenderest sympathy, in this, the hour of their affliction, and that in testimony thereof a copy of these resolutions be forwarded to them.

Resolved, that these resolutions be appended to the minutes of the Council and be published in the TRANSACTIONS of the INSTITUTE.

The resolutions were unanimously adopted.

THE CHAIRMAN:—The regular business of the meeting is the reading of papers. The first paper is by Mr. Hermann Lemp, Jr., on the "Local Annealing of Hard Faced Armor Plates."

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A paper presented at the one-hundredth Meeting of the American Institute of Electrical Engineers, New York and Chicago, October 23d, 1895.

LOCAL ANNEALING OF HARD FACED ARMOR PLATES.

BY HERMANN LEMP, JR.

Every one is now more or less familiar with the Thomson Electric Welding process, which in past years has been introduced into almost every metal industry, in one shape or another. This process created a new field in the technical application of currents of large volume and small E. M. F., a field which, while it was primarily intended for welding, naturally suggested a number of other applications to so fertile an inventor as Prof. Thomson; and so it happened that early in its fundamental inception, the use of large currents was contemplated to be utilized for heating plain metal bars or parts of sheet billets, etc., for forging purposes, to rivet, upset, to temper or withdraw the temper, or to be worked upon in any well-known manner while being kept heated by the current.

It has been the good fortune of the writer to lately work out one of these novel applications, and since the literature concerning this branch of electro-technics is somewhat limited, he has thought it advisable to bring an account of the same before the INSTITUTE.

One of the latest advances in the making of protective armor for battle-ships, or even forts, has been the introduction of what is known as the Harvey process. For those not conversant with the latter, I will briefly state that it consists in taking an ordinary low carbon steel plate and introducing an additional percentage of carbon into the surface metal, thus changing the crust to the depth of about an inch, into a steel resembling tool steel. A plate thus treated, is lastly water-hardened, similarly to an

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ordinary tool, and by experience has shown to offer, under equal conditions, more resistance to the impact of a projectile than any other armor known, and therefore we will take this as an illustration of hard faced armor. The extreme hardness of the surface of a Harvey plate, while exceedingly valuable in preventing projectiles from piercing it, has a disadvantage when it is required to be pierced by a drill and tap. Such holes may be required either for fastening ladders, swivels or other appliances to the hull of the vessel, or to fasten T flanges supporting the deck to barbettes or turrets.

The methods heretofore used to produce these holes were principally two:

1. To protect the surface of the plate in patches or strips, to prevent carburation, wherever holes were expected to be drilled.

2. To make accurate drawings and patterns of each plate beforehand, to which all holes are drilled before plate is hardened.

Plan No. 1 was practiced in the United States until it had to be abandoned. In practice it was found that numerous alterations in construction, errors in either draughting-room or mills, made it necessary to pierce holes where no provisions for annealing were made. It also happened quite frequently, that the method for prevention of carburation did not always work satisfactorily, and while white paint indicated well enough where soft metal was expected, very often hard metal was actually found. Hence it was patent from the first that some process was needed to rectify errors of this kind. Experiments were then made with the oxy-hydrogen blowpipe, or the electric arc, to anneal such spots as required to be drilled, and numerous mechanical devices for drilling, with drills of every design and method of tempering, were tried, until it seemed that the case was without a remedy.

It was at this stage that the problem was referred to the Thomson Electric Welding Co. of Lynn, and experiments were immediately undertaken to solve it. The process and apparatus necessary to carry it out, all resulting from the experiments undertaken, will be described presently.

The second method, which is used in England, has the advantage over the first, that there is no difficulty in carrying it out, provided there are no alterations made, and no errors committed. The present method of construction seems to be, to make, beforehand, a complete *model* of the vessel to be built; then make

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accurate drawings and full-size patterns of every plate, giving the exact location of every hole. These are then bored, tapped and countersunk to a depth of approximately $\frac{5}{8}''$ and of a much larger diameter, filled with clay, and then the plate as a whole is heated and hardened with water. (See Fig. 1.)

This method works apparently all right, although in spite of drawings and models, errors are made. There is no doubt, however, that it is a slow and very costly method of working, and would hardly ever be resorted to in the United States.

From the above it seems clear that there has existed a need for a process by means of which isolated spots, regardless of location, might be annealed so as to permit drilling and tapping.

If, by sending a current of large volume through any spot thus to be treated, the spot is brought to a temperature of approximately 1000° F., there can be no doubt that the temper has been withdrawn. Experiments carried out to that effect at once

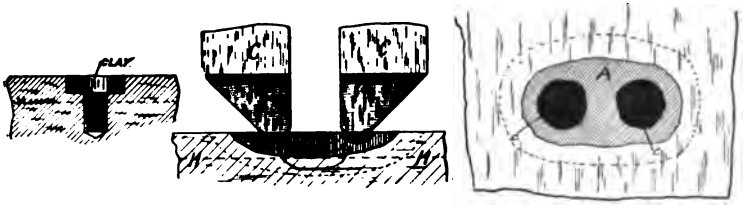

FIG. 1. FIG. 2. FIG. 3.

showed, however, that upon taking off the heating current the heat was so rapidly conducted away by the surrounding metal masses as to cause the heated spot to become chilled just as effectually as if it had been plunged into cold water. No method of outside protection of the heated spot would prevent this, and the *gradual* cooling of the spot had to be attained by different means: namely, a gradual and slow withdrawing of the heating current. The method of introducing the annealing current is best shown in Fig. 2.

C C are two copper contacts cooled by water circulating inside. The current enters the plate by one end, and leaves it by the other. Right under the contact, the metal comes to a bright cherry heat, (shown in black) while the portion intervening and partly surrounding the contacts acquires a temperature of just a visible red. Line H H indicates where the influence of the Harvey treatment stops.

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The shaded portion in Fig. 2 and 3 shows the zone softened and ready to be machined, while the dotted line shows how far the heat radiation would cause the metal to turn blue. When cooled, the annealed portion shows a chocolate color, while the place where the contacts have been resting, is scaled and hard, and cannot be touched by a tool to a depth of about $\frac{1}{4}''$. These places can again be annealed later on, if required.

The apparatus necessary to carry out this process consists of the generator, the annealer proper (transformer) and the regulating apparatus.

The generator is commonly a separately excited alternator of variable potential, of a maximum of 300 volts and 100 amperes. The frequency, preferably, should be low, 50 cycles per second being used. When more than one annealer is to be run simultaneously from one generator, constant E. M. F. of the latter should be used, and each annealer regulated separately by a reactive coil. The annealer proper is a transformer similar to the well-known welding transformers. As the apparatus is to be operated outdoors, on board of vessels during construction, it is important that the same may be handled with immunity from electric shocks, even when operated in mist and rain.

To meet these conditions a copper-clad type of transformer is used, one in which the secondary is composed of two copper castings each having a rectangular groove, which two halves, when bolted together, form a closed rectangular frame in which the primary is held enclosed. The hollow space intervening between primary and secondary is moreover filled with a heavy oil, which acts both as the insulator and conductor of heat from primary to secondary. The secondary, by completely surrounding the primary, affords an excellent mechanical protection, and prevents electric as well as magnetic leakage. The primary is a copper ribbon insulated with asbestos, and the ratio of conversion is 100 to 1. The transformer has two trunnions fastened to its sides, in a line a little above the center of gravity, which trunnions swing in bearings, part of a yoke which straddles the whole. The yoke in its turn has a hook which may be secured to the latter at any place of the arch, thus allowing the transformer to be suspended, like a compass in gimbals, in any position desired.

It goes without saying that the copper castings which compose the secondary are cut through at one place in the circuit. On either side of the cut, two short platforms form the base for copper

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contacts of various shapes and sizes, by means of which the currents are made to enter and leave the plate to be annealed. These copper contacts are of forged copper, hollowed out to receive water circulation for cooling purposes, and terminate in narrow tips rounded at the end.

The weight of the whole annealer, being approximately 1000 pounds, is sufficient to give proper contact pressure for all work on a horizontal plate. When inclined surfaces, vertical or otherwise, are to be worked upon, the transformer is suspended so that

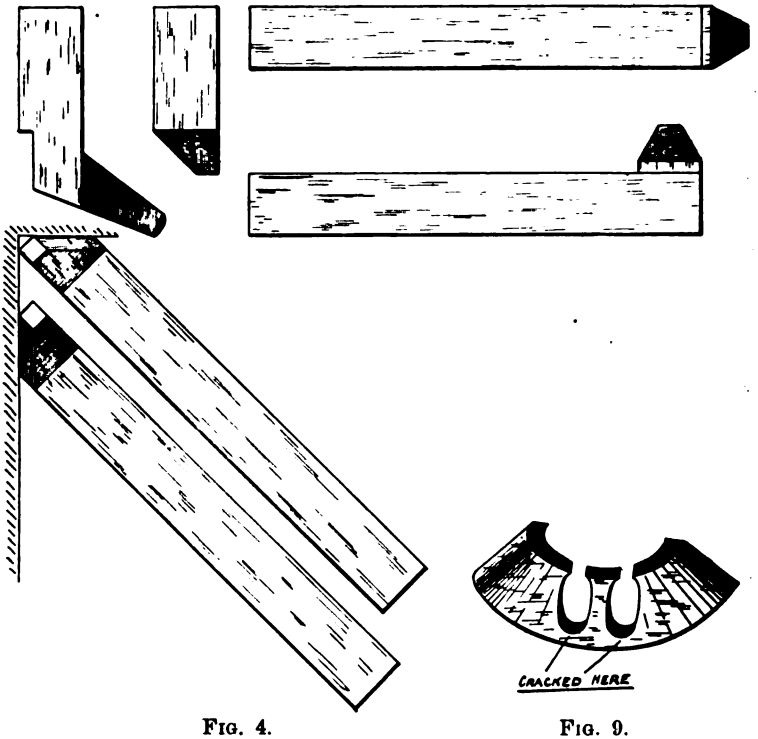

FIG. 4. FIG. 9.

its weight shall not interfere with the contact pressure, which is obtained for work by bracing the contacts directly with wooden wedges against any object near by. On the outside of a hull, it is proposed to use a pair of electro-magnets, which are made to hold themselves against the iron hull, and form a support for the annealer. Fig. 4 shows some of the various shapes of contacts that are used in various positions.

The remarkable thing is the great amount of current that is

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being carried by the copper contacts into the plate. The contact surface is seldom more than about ½" square, and yet 10,000 amperes are made to flow through it continually. This is equivalent to 40,000 amperes per square inch, a density which is only possible on account of the thorough cooling by the water circulation.

The regulating apparatus is in most cases simply a rheostat in series with the field of the generator. When more annealers than one are run simultaneously from one generator, as mentioned before, a reactive coil is interposed between the two, and this latter has been made automatic; that is to say, provided with a dash-pot, which permits the current to be reduced uniformly and at any given rate it is set for.

This reactive coil, Fig. 5., is composed of a solenoid coil of cable, well insulated, having a movable laminated iron core which is raised out of the coil by means of a leather strap and winch. The core is composed of thin iron strips placed side by side around a circle, and projecting radially from the same, and being held on top and bottom by a slate disk, in a manner similar to the securing of the copper segments of a commutator. No insulation of the core is necessary, and good ventilation is obtained. The core once raised out of the coil tends to return by gravity and the attraction of the solenoid, but is checked in its descent by a pair of dash-pots, one on each side of coil. These latter communicate with each other, top and bottom, and have one of the pistons provided with a valve which opens when the core is raised, and closes when the core descends. The dash-pot cylinders are filled with a light mineral oil, which does not freeze nor clog under any ordinary conditions of temperature. An adjustable by-pass valve allows the oil to flow from the tube to the top side opposite. By opening or closing this valve more or less, any rate of descent and, consequently, diminution of current, can be uniformly obtained, without requiring any skill on the part of the operator.

The annealing operation is carried out as follows: The transformer is placed in position, the contacts touching the plate either side of the place marked to be annealed, and the primary current brought up by means of a rheostat to from 75 amperes to 90 amperes for about two minutes, according to the size of spot to be annealed, which will bring the metal to a dull red heat, a temperature at which a pine stick catches fire when held in

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contact with the plate. If no reactive coil is used, the current is now diminished by turning the rheostat one point every minute. If the reactive coil is used, the core is now raised by winch, the coil put in circuit by opening a short-circuiting switch, and then

FIG. 5.

FIG. 6.

FIG. 7.

is allowed to descend on its own account. The operation generally takes *seven minutes*, all told. Accompanying Figs. 6, 7 and 8 show the proper apparatus in operation on the "Massachusetts" and "Oregon." No difficulty has been experienced

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from the beginning. The annealing of individual spots was, however, only the stepping-stone to a more important work of a similar nature, work which was about to be given up, owing to what were considered insurmountable difficulties.

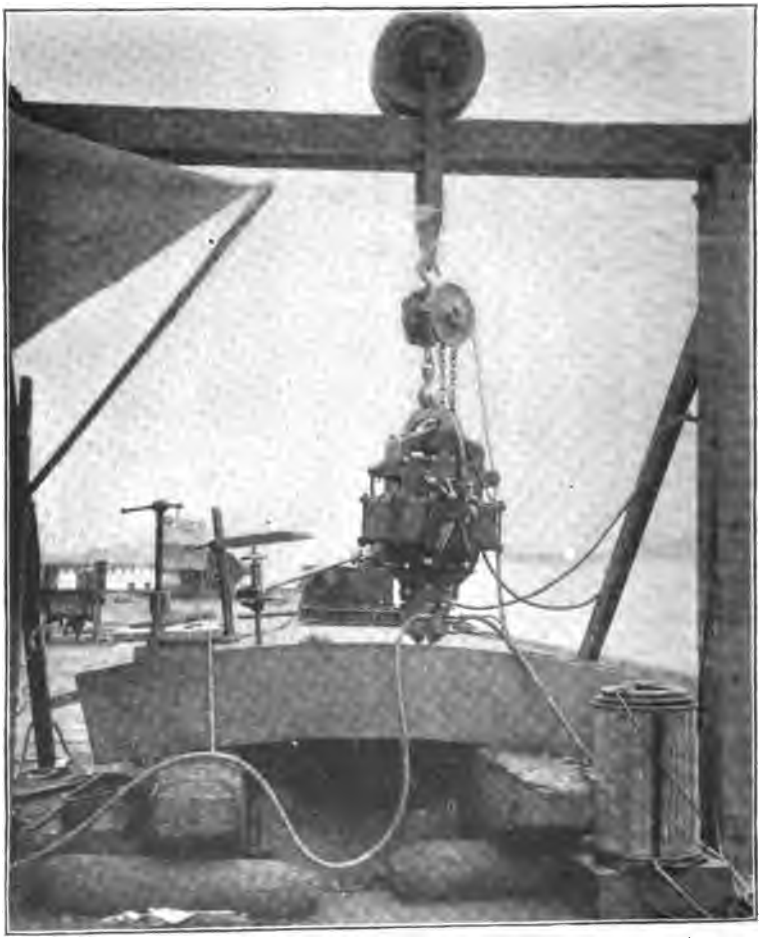

FIG. 8.

In the construction of a modern man-of-war, there are many armor plates which act as shields to the guns, and have to be perforated to allow the gun muzzle to pass through and to be either raised or lowered. Some of these shields are circular or

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oval, with narrow edges around the ports, in the case of Harveyed plate. To perforate these shields after carburation, and before being water-hardened, was the only possible way, since previous experiments had shown that prevention of carburation could not be relied on, and no process was known to anneal the plate locally after hardening. The hardening of a plate once perforated, showed itself to be, however, almost impossible; in fact, a matter of chance. In most cases the plate cracked in two as shown in Fig. 9, or the whole plate became distorted in such a way that it could not be used. As individual spots

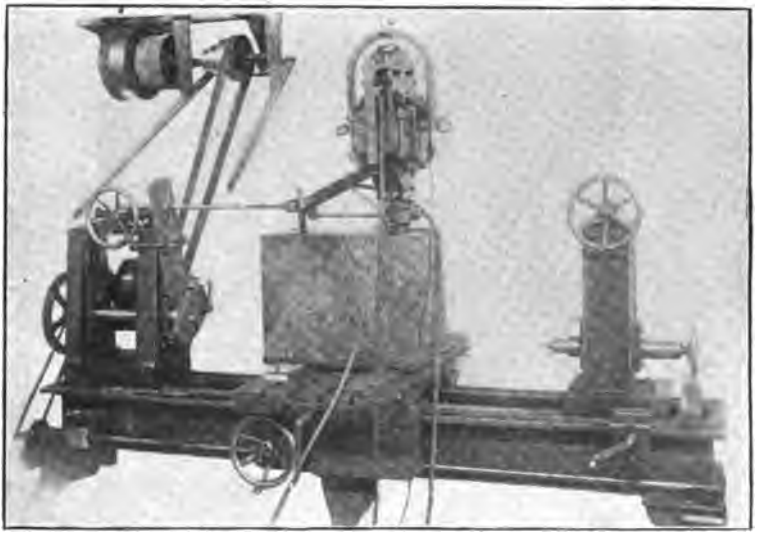

FIG. 10.

for holes could be annealed, there could be no doubt that a series of annealed spots could be likewise obtained by the electric process, following a line along which a cutting tool was expected to be run. The first attempt, therefore, and made in England, was to anneal a number of spots in proximity to each other in such a way that the annealed zones should overlap each other.

As described above, it is very important that the temperature of any individual part should be gradually and slowly withdrawn; and while for individual spots the only possible way to do this was by gradually diminishing the current, it was obvious that when a line was to be annealed, instead of annealing a number of spots side by side, the same effect of withdrawing the heat

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gradually from one portion could be obtained by moving the apparatus itself relatively to the plate to be treated. The rate of this movement, of course, depended upon the rate at which the temperature should be allowed to fall in any particular spot to prevent chilling. The apparatus was therefore arranged to be moved along a line to be annealed, the motion being obtained by an ordinary screw and nut held in a bracket, the nut being turned at a predetermined rate controlled by a watch. It was found that a speed of about ¼″ per minute was sufficiently slow to ensure thorough annealing.

Fig. 11.

The copper contacts were of the simplest kind, as described above, bedding themselves partially in the surface, and when being dragged along by the screw and nut, raised in front of themselves a burr or chip similar to a planing tool. After a whole day's continuous use the copper contacts were found intact, while a number of chips from the steel surface were lying about. We thus had the peculiar phenomenon of a hard steel chip cut with a copper tool.

Upon the completion of the work, it was found that a strip about 2¼″ wide throughout the length over which the machine

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had been moved, could be operated upon by drills or a shaper, in a manner as easily as if it had never been hardened before.

In the work just described, the apparatus was moved about, but in regular practice it would be better to construct a machine consisting of a large bed, on which the plate to be treated may be fastened and moved in any direction automatically at a predetermined speed, while the annealer proper is suspended in a given position above the plate, as shown in Fig. 10. The annealing operation occupies but a small percentage of the time required for the cutting.

Fig. 11 gives a view of a sample plate annealed by the method described above, and cut out to represent a port-hole as is used on the turrets of a man-of-war.

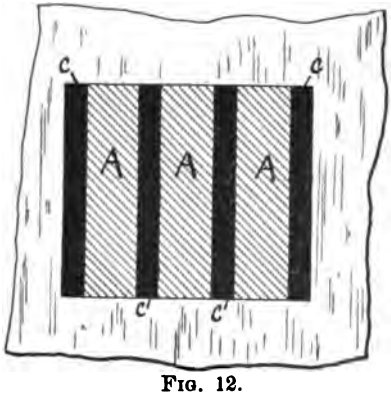

FIG. 12.

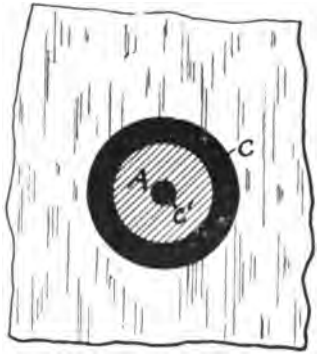

FIG. 13.

It is unnecessary to state that when the apparatus is used for continuous annealing, the primary current is kept at a nearly constant value, the diminishing of heat at any individual spot being obtained solely by the moving of the apparatus from it.

As mentioned before, the places where the contacts are passing over the plate, being brought to a higher temperature than any other, remain hard. Experience has demonstrated, however, that they may be re-annealed later on, by treating the spots in the same way as any other hard spot on the plate. By this means we are therefore able to anneal any shaped portions, not merely lines. This is best seen in Fig. 12, in which a series of strips are annealed side by side (shown in shaded lines A.) The hard faced surface is then removed on such places by a planer and drill; the machine is then run a second time over the annealed strips, rest-

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ing it this time on the bottom of the groove and on the softer metal, thus annealing the ridges c left between the annealed strips, on which ridges the contacts were running previously. When all these strips are annealed they may be removed by machine tools without any further difficulty. In a similar manner a large round place may be annealed, as shown by Fig. 13. The transformer is set on the plate, one contact resting on c′, the other at any other place in circle c; the apparatus is then slowly revolved around contact c′ as a center, until the second contact has completed the circle c. The shaded portion A represents now the annealed surface, which is removed by a cutting tool. The contacts are then made to rest on either side of the center c′, and the latter is annealed and removed in its turn.

The apparatus may also be used for the reversal of the annealing process; that is to say for creating isolated hard spots in soft tool steel by sending a current through the spot to be hardened until it reaches a bright cherry heat, and then suddenly removing the current or machine.

Various other applications will suggest themselves in the operation of this process, already adopted by the United States Government. It may be used in the construction of burglar-proof safes, for dies and punches, for projectiles, and other articles of a similar nature.

Discussion.

The Chairman:—This paper embodies one of those novel applications of electrical energy in which it is perhaps our function to interest ourselves even more than in the established uses. It is these very new applications which deserve special recognition.

The point which strikes me is that Mr. Lemp is enabled to pass 40,000 amperes per square inch through a contact, of course cooled by means of water; but the mere fact that it is possible to pass such an enormous current density through a contact is certainly interesting, and I should imagine might be very useful in certain cases.

It is also interesting to observe that a current is produced in the secondary of the transformer, and that this illustrates the flexibility of electrical applications—that a secondary which consists merely of a ring of metal with an opening in it, so to speak, is employed to produce the necessary current.

This interesting subject is open to discussion.

Mr. Edward P. Thompson:—While I was listening to the paper, I wondered whether it would refer to the applicability

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of the process to the opening of safes, and I noticed that it is allnded to in the last paragraph. I remember where a bank, only a few years ago, had paid thousands of dollars to have a burglar-proof safe put in. When they came to change the bank building, the safe manufacturer wanted them to put in a new safe. The President argued with him and said "That is a good safe; what is the matter with that?" "You see" was the answer "those doors don't come together with sufficient closeness, there is a crevice there which forms a basis upon which to use dynamite." So remembering that, I would be glad to hear what Mr. Lemp has to say as to those challenges that the manufacturers of safes offer. "There is a safe that it is absolutely impossible for anybody to break open," says the manufacturer, and it seems to me that Mr. Lemp could take one of his annealers and soften the surface to a sufficient depth to drill, and to introduce dynamite.

Mr. A. E. Kennelly:—I would very much like to ask Mr. Lemp if he can give us any figures as to the resistance offered by those two contacts. They are contacts of very limited area, are very hot, and the iron between them is very hot. If he would tell us how much pressure he uses in the secondary circuit of the transformer, and what the resistance of that portion of the circuit is, I think the information would be very useful.

The Chairman:—I think it might be well to answer the questions as they present themselves, Mr. Lemp.

Mr. Lemp:—In answer to Mr. Thompson, in reference to the opening of safes for the introduction of dynamite, I think it would be rather a hard thing to carry a transformer weighing 1000 lbs. to a place in the night (laughter), still if it is simply wanted to prove to the manufacturers of safes that a hole can be made through their plate if the latter is obtained by using tool steel, water hardened, there is no reason why it cannot be annealed by this method and drilled through with an ordinary drill; if, however, a different substance is used which does not allow annealing through heat, the process would be of no value.

In answer to Mr. Kennelly, I have never measured that resistance. I would say the weight of the apparatus, a thousand pounds, is sufficient to ensure contact, to pass the current through. As shown by the illustration in Figs. 2 and 3, the portion in black shows the metal raised to the temperature of a white heat, owing to the crowded state of current at that point. Of course, the copper contacts themselves are cooled by water, but the steel you cannot cool except through the medium of the copper contacts, and that is not sufficient. Still, if the contacts, to start with, are made pointed, there is no difficulty about passing the current through. They bed themselves right in the metal. If they are made exactly flat and ground, there would be lots of sparking but no contact, probably because the contact pressure is not sufficient in that case, when relying solely on the weight of the apparatus.

Mr. Kennelly:—The electromotive force in the secondary is how much?

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MR. LEMP:—About two volts. It can be raised to three volts.

THE CHAIRMAN:—That would give the necessary data, would it not, if the resistance of the secondary circuit were known?

MR. LEMP:—The current, again, has never been measured; it has simply been computed from the primary current. We are passing 100 amperes through the primary circuit and the E. M. F. is about two.

THE CHAIRMAN:—The data are contained in the circuit, provided of course, the values of current, etc., are reasonable, and the resistance of the secondary is known. Is the resistance of the secondary measured or measurable?

MR. LEMP:—It is measurable, yes, I have never measured it.

THE CHAIRMAN:—I presume, compared with the contact of resistance, it is small.

MR. LEMP:—It is very small.

MR. F. A. PATTISON:—I would like to ask Mr. Lemp, whether he has ever compared the surface contacts when the terminals are pointed and when they are flat, and in that case whether when they are pointed, the surface contact is very much larger than in the other case.

MR. LEMP:—The contact proper is never much more than half an inch square. To start with it is merely a point, and the heat immediately raises the surface of the iron into contact with the copper—a little hill forms itself, so to speak. The flat contacts were not so satisfactory for the reason that the pressure could not distribute itself evenly when only the weight of the transformer was used for obtaining the contact, and for this reason they were abandoned.

DR. EMERY:—What are the dimensions of those copper points there?

MR. LEMP:—The tips themselves are not more than one inch square. The copper contact itself is three inches square; by that I mean what we commonly call the contact—the whole piece of copper which is secured to the transformer; but that part which touches the armor plate and which really is the contact proper, is not more than one inch square, and being rounded, the contact surface is not more than approximately half an inch square.

DR. EMERY:—Is it rounded globularly or cylindrically?

MR. LEMP:—It is a segment of a ball.

MR. W. W. KER:—I would like to ask regarding the amount of space heated, when about 75 amperes are used, and also when you increase this current to say 10,000 amperes, what is the distance between the contact points.

MR. LEMP:—Seventy-five amperes are used when the hole to be annealed is not more than about $1\frac{5}{8}''$. When the full dimension is used like $2\frac{1}{4}''$ then the current is increased to from 90 to 100 amperes. Of course one thing to be considered is, that this being an alternating current, and passing through a large iron

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plate, the energy actually employed cannot be computed from the current and E. M. F. It is considerably less where 90 amperes are used, the energy measured by a wattmeter is about 16,000 watts.

MR. E. P. THOMPSON:—Is the metal immediately surrounding the hole that is made, injured by its being annealed? Say that you anneal a certain portion in order to be enabled to drill the hole, I suppose it is impossible to anneal only just that portion of area equal to the whole. Therefore there would be some soft metal immediately around.

MR. LEMP:—The zone of annealing is somewhat larger than the place actually required; in other words, surrounding each contact there is a little zone of annealed steel. Right under the contact the metal is somewhat blistered and remains hard to a depth of about a quarter of an inch. Below this depth it is soft again. No injurious effect has been found in the iron.

DR. EMERY:—I would like to ask, if the contacts harden the metal, how the points where the contacts were first located can be annealed, without making other hard spots. Excuse me; in formulating my question I realize that the points do not harden the metal, but, being cool, they simply prevent the plate from being heated, so if they are moved to a place already annealed, they will not harden it.

MR. NELSON W. PERRY:—In the Harvey process, I understand the process is very similar to what is known as the cementation process in the manufacture of crucible steel, only in that case they use a wrought iron bar, and pack it in carbon and raise it to a high temperature, and hold it to that temperature for a sufficient length of time, and through a sort of endosmotic action, the carbon is absorbed by the surface of the bar and it is made exceedingly hard. In the Harvey process, I understand that they start with a mild steel and introduce additional carbon on the surface. Now there is another process in metallurgy by which they take a high carbon substance, such as gray cast iron, and pack it, not in carbon, but in an oxidizing substance, such as the oxide of iron and bring it to a high temperature. It has reverse action—it takes the carbon out and reducing its quantity, makes it malleable again. That is in general the process which is known as the malleable cast iron or cast steel process. From Dr. Emery's question it occurred to me that in case it was desirable to permanently take the high temper out of these hard spots after annealing, that they might interpose an oxidizing substance between the surfaces of the contact and the steel, so as to draw out a certain portion of the carbon and make it a lower carbon steel.

MR. TOWNSEND WOLCOTT:—I scarcely think that would work in seven minutes. The malleable iron process takes a good many days.

MR. PERRY:—That is because the temperature is very low.

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But go into a foundry whenever a cast is made, and you will notice those blue flames, which are due to this very process taking place very rapidly, the oxidizing substance in this case being atmospheric oxygen. The rapidity of carburation or decarburation is some function of the temperature, and with that of the electric arc would be very rapid. I see no reason why the decarburation of a thin superficial layer under the conditions named might not be sufficiently rapid for practical purposes.

DR. EMERY:—Mr. Chairman: The answer to my question occurred to me as I asked it. I attempted to explain that the points do not harden the metal; being cooled they simply prevent annealing, and if placed on an annealed part of the plate it will remain soft.

[COMMUNICATION SUBMITTED BY MR. LEMP AFTER ADJOURNMENT.]

To answer more completely the questions put by Mr. Kennelly and Dr. Crocker, in reference to the contact resistance between the electrodes and the armor plate, I have made on my return to Lynn the following experiment:

The transformer was set upon a block of 18″ Harvey plate, with a distance between the tips of contacts of 2¼″, and a current of 90 amperes allowed to pass through the primary for approximately half an hour.

Inasmuch as the resistance of the contacts to be measured, causes considerable heating of the contacts, and this heat is carried away by the water cooling, this water cooling was made the means for determining the approximate resistance of the contacts. The water which was allowed to circulate through the contacts, was carefully measured for temperature before it entered, and when it left; and in this manner thermal units determined, which were lost through the contact resistance.

While it is true that not all the heat is properly attributable to the contact proper, and some of it is to be charged to the radiation from the heated surface, still this item is nearly enough balanced by the loss of heat of the contacts proper. The energy put into heating the water will therefore be a fairly good estimate of the heat caused by the contact.

The following data were obtained:

Current in primary.....90 amperes.
E. M. F. " " .....200 volts.
Energy as measured by wattmeter....15,698 watts:

8.4 lbs. of water passing through the contacts per minute were raised from 17° to 33°. From the above, total thermal units, 241.9, or a loss of 5.7 H. P. in both contacts. This was equivalent to 4352 watts for both contacts, or 2176 for one, and the current passing through the secondary being 9000 amperes, the resistance of one of the contacts is equal to .000026 ohms.

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After the completion of the experiment, contacts were carefully inspected, and it was found that a circle of approximately $\frac{3}{4}''$ had been in actual contact with the armor plate, which with the current density of 9000 amperes would give a density of 19550 amperes per square inch. While this is not as dense as intimated in my paper, it represents the normal condition, whereas 40000 is a condition which occasionally happens, without however any injurious effects.

THE CHAIRMAN:—Is there any further discussion or are there any more questions to be asked in reference to this paper. If not we will proceed to the consideration of the next paper on the programme, "The Rating and Behavior of Fuse Wires" by Professor Stine, Mr. Gaytes and Mr. Freeman of Chicago. This paper having been sent to the members in advance it will only be necessary for the Secretary to call attention to certain of its points, that being the advantage of issuing papers previous to the meeting.

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A paper presented at the One hundredth Meeting of the American Institute of Electrical Engineers, New York and Chicago, October 23d, 1895.

THE RATING AND BEHAVIOR OF FUSE WIRES.

BY W. M. STINE, H. E. GAYTES, AND C. E. FREEMAN.

It is with a certain feeling of hesitation that the attention of the general engineering profession is again called to a series of investigations relating to the well-worn subject of fuse-wires. Within the past few years a number of able papers on the subject by Messrs. Jackson and Ochsner, Mr. C. P. Matthews, and others, have been presented to the INSTITUTE. These have ably supplemented the work of Preece and other foreign investigators, and at the same time developed some points hitherto neglected. The latest contributor to this subject has been Mr. W. E. Harrington, who employed the circuit-breaker in his tests. The literature of the subject has been further increased by several excellent theses emanating from our leading technical schools. The bibliography, too, of this subject, has already been referred to in the TRANSACTIONS of the INSTITUTE.

However, the thermal cut-out is still one of the most unreliable of the many devices employed on electric circuits. Its use is universal, but beyond a few practical details the device is but little understood. The blocks in which they are used show some slow improvement, but most of this has been due to the vigilance of insurance boards, and they are still far from perfect. As a source of vexation and uncertainty, the fuse is probably unrivaled.

An analysis of the literature of the subject shows that the theory of the thermal cut-out has been thoroughly investigated. The elements entering its action have been carefully studied and incorporated into fairly satisfactory equations. Yet all tests and treatments have shown the thermal cut-out to be subject to such variations and modifying influences that but

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little of practical value can be deduced from analytical investigations.

These considerations led the writers to attempt further investigations. The fuse was dealt with as an auxiliary to electrical circuits, and its behavior under such conditions was carefully studied. The work in great part bears on points already treated of, but it was considered best to study the entire subject afresh, and endeavor to present a more or less complete discussion of the behavior of some of the ordinary alloys employed in practice. Naturally, the data obtained has been voluminous, in all some 1300 determinations; but great care has been taken to thoroughly check all results.

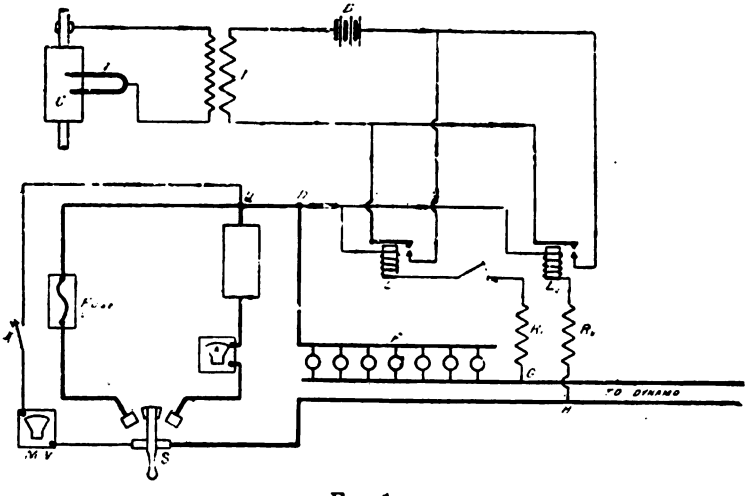

FIG. 1.

The Apparatus.—Fig. 1 is a plan drawing of the main and auxiliary apparatus, with all connections indicated. One of the dynamo leads was brought to the switch S. This switch was especially designed and constructed for these tests. The pivot was placed well toward the handle to make the travel of the blade as rapid as possible. The carbon rheostat, C. R., was built up of carbon plates, whose contact resistance was readily varied by screw pressure. The fuse was tested in a large box lined with asbestos, and open at the top, permitting of inspection and access, while at the same time protecting the fuse from draughts. The lamp rack, P, held 100 16-C. P. 110-volt incandescent lamps. These were connected in groups to switches, which enabled any

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combination from 1 to 100 to be used. A step-by-step rheostat in multiple with this rack was used to adjust the current through the interval of one lamp.[1] By its use the current could be accurately adjusted within the limits of .4 and 60 amperes. For higher currents several similar racks were placed in multiple: L_1 and L_2 were small "pony" relays of 20 ohms resistance, having in series with each, five 16-C. P. 110-volt lamps, (R_1 and R_2) These relays worked on a current of about 10 milliamperes each, and were wired to close the circuit through the primary of the induction coil I. Two storage cells furnished the current for these relay circuits. T was an electro-magnetic tuning-fork driven by an independent storage-cell; C an iron chronograph drum which was turned by hand. The secondary or spark circuit of the induction coil was connected to the tuning-fork and the chronograph drum respectively.

Method of Experiment.—The current to which the fuse was subjected during the test was first measured accurately by throwing the switch on contact O, and passing it through the Weston ammeter, A. Both the circuits passing from the jaws O and N of the switch to the point of conjunction Q, were short, and of No. 4 A. W. G. wire. It was thought best to take the resistance of the fuse into account, and adjust the resistance of the ammeter circuit to exactly equal that of the fuse circuit. To accomplish this, a current smaller than the known fusing current was sent through the fuse, and the fall of potential from S to Q noted on a Weston milli-voltmeter. The current was next switched on the ammeter circuit and the fall over this from S to Q, was made exactly that over the fuse circuit, by adjusting the compensating carbon rheostat. The fusing current being accurately measured was switched over on the fuse. The fusing time was thus accurately ascertained. The lamp rack being a non-inductive resistance, the time interval for the current to rise to its full value on the fuse is negligible for all but the very shortest periods. The resistance of the bank of incandescent lamps could not materially alter during the quick throw of the switch, which was thrown by striking it a blow on the handle. Frequent observations made on the lamps did not reveal even the slightest tremor of the light when the switch was thrown. To render the point more certain, the time interval between the break and make of the switch was accurately determined chronographically, and found

1. For illustrated description of this lamp-rack see *Electrical Review*, New York, October 24, 1894, p. 201.

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to vary between $\frac{1}{700}$ and $\frac{1}{1200}$ of a second. The fusing times were noted on a stop watch for all periods exceeding one second. For shorter periods the chronograph arrangement was used. The tracings of the electro-magnetically driven tuning-fork T, were made on smoked paper fastened over the drum C. This fork was always rated before each set of experiments, by switching it in circuit with a standard second clock. Its rate was about 67 double vibrations per second. By frequent timing, all changes in rate due to temperature, etc., were noted and allowed for. The amplitude of the fork was large enough to allow periods of less than $\frac{1}{1300}$ second to be accurately measured. The records on the drum were made by sparks from the induction coil upon the breaking of one of the relay circuits.

The action of the relays was as follows:—When the switch was on O, L_1, was closed and L_2 open; when the contact was broken at O, L_1, opened, throwing a spark on the drum, and L_2 closed. The switch making contact at N, L_1 closed and L_2 opened, making the second spark record. When the fuse blew, L_1 opened, causing the third spark record. Though both relays acted synchronously, there was an interval during which the current through coil I was completely broken. Two distinct records were made in every case. The interval between the first and second sparks gave the period of open circuit for the switch, while the interval for the second and third sparks gave the fusing times. The relay circuits are indicated with sufficient clearness on the diagram.

The Experiments.—As our experiments were designed to exhibit the behavior and characteristics of the fuse used for protecting electrical circuits, it was considered best to adopt not more than two brands of wire for all the tests, rather than employ a large number of varieties. Other investigations have shown that the various makes of fuse wire closely resemble each other in behavior, and the conclusions obtained with one wire would be general for all. The first make of wire was purchased from supply houses, the second was furnished by the manufacturers.

First Series.—These tests were made under conditions which we shall call commercial, or those which obtain in practice. In all cases the fuse wire was carefully inserted, so as to obtain a uniform pressure of the wire under the screw head without unduly crushing it. The same block was used repeatedly, and little care taken to keep the terminals clean. This was done to more nearly imitate practical conditions. In only two or three cases

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out of hundreds of fuses blown did the rupture occur at the contact. Two classes of porcelain cut-outs were employed; one was the open porcelain base "main line" style, the other the closed porcelain "K. W." variety. In the latter, the 10-ampere size has a space of only ½ inch between its terminals, though the fuse is suspended out of contact with the porcelain base. This style of block has recently been condemned by the underwriters, and very properly. With the terminals so close together, a fuse blowing at 20 amperes invariably establishes a vicious arc, and the terminals melt with such explosive violence as to frequently shatter the block. Though the open type of block has an added fire risk, the terminals are, as a rule, further apart. A pronounced fault in their construction is that the terminals are let in flush with the surface of the porcelain. Nearly all types

TABLE I.

FUSING CURRENTS IN AMPERES.—LIMITING TIME 1 MINUTE.

	A ½ Amp.	A 1 Amp.	A 2 Amp.	A 3 Amp.	A 5 Amp.	A 10 Amp.	A 15 Amp.	B 4 Amp.	B 8 Amp.	B 12 Amp.
Covered Block, ½ inch ...	2.5	5	10	14	20	35	—	13	—	—
Open Block, ⅞ inch	3	5	9	10	15	25	—	—	—	—
Open Block, 1 7-16 inches.	—	—	—	—	—	—	30	—	—	—
Open Block, 8 inches Vert.	1.5	3	5	6	9	14	20	—	7.5	10
Open Block, 8 inches Hor.	2	4	6	7	11	—	20	—	—	—

of porcelain fuse-blocks merit severe criticism on several points. The terminals are too close together in small sizes, the fuse often resting on the top or base; and their mechanical construction is very poor. Too little attention seems to be given to the proper function of a fuse-block in its design.

Table I needs but little comment. It clearly shows the unreliability of the porcelain fuse blocks used, and also the imperfect commercial rating of the fuse wire, A. The limit of fusing time was 60 seconds. Fuses larger than five amperes will often blow in from one to three minutes on a current somewhat less than stated, but this correction is so slight for these results that it need not be seriously considered.

Second Series.—The open eight inch block was adopted to avoid all cooling effects from the terminals. When used horizontally, the fuse rested on a number of thin asbestos supports

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let into grooves one inch apart, the fuse being elevated one inch above the base of block. In those tests in which the block was placed vertically, hydrostatic pressure lowered the fusing point, but when used horizontally the data may be regarded as the normal fusing points for these various wires.

The data of Table II will be clearly understood from the accompanying legends. One of our objects was to accurately measure the fusing times for abnormal currents. It is characteristic of all electro-thermal devices that they are sluggish in action. Cases may arise in practice where the insulation of wires

TABLE II.

FUSING TIMES IN SECONDS.

Amp.	I.	II.	III.	IV.	V.
15	84	75.8	—	—	—
20	36.6	35	—	—	—
25	19	17	60	45	195
30	12.8	10.8	33	26	41.6
35	9	7.6	20	16.4	30
40	7	5.8	14	12.6	25
45	5	4.8	10.4	9	17
50	4	4	9	7.4	13
55	3.6	3	6.6	5.8	—
60	3	2.6	5	5	8
65	2.8	2.2	4	4.6	—
70	2.8	1.8	3.6	3.6	5.4
75	2	1.6	3	3	—
80	1.8	—	—	2.6	4.8
85	—	—	—	2.2	—
90	—	—	—	2	3.6
95	—	—	—	1.8	—
100	—	—	—	1.6	3.2
105	—	—	—	1.4	—
110	—	—	—	1.2	2.8

I.—20 Amp. B. Horizontal 8 inches Mica supports each inch.
II.—20 Amp. B. Vertical 8 inches.
III.—20 Amp. A. Horizontal 8 inches Asbestos supports each inch.
IV.—20 Amp. A. Vertical 8 inches.
V.—25 Amp. A. Vertical 8 inches.

is forced to become a fuse competing with the metal supposed to protect the circuit. In all such cases it is only a question as to which shall yield the sooner. There is sufficient evidence in this table to explain why a fuse does not always protect an armature from burning out. The table becomes the more significant in this light when it is noticed that the data has been obtained by the use of an abnormally long fuse block. With the commercial block, the fusing times were increased many fold.

The results plotted in Fig. 2 are significant. The upper curve was obtained from three-ampere fuses in the covered block. The curve is here more sharply marked than in the case of the

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same wire blown in an open block. This was found to be true for all sizes of wires tested in this manner, and indicates that a fuse is more sensitive in a covered than in an open block. In this case the shorter distance between the terminals raised the fusing point, and increased its inertia for higher currents.

It was considered desirable to obtain data which should exhibit the action of the fuse with the cooling effect of the terminals eliminated. To accomplish this, the fuses were blown in lengths of eight inches, with asbestos supports placed each inch of

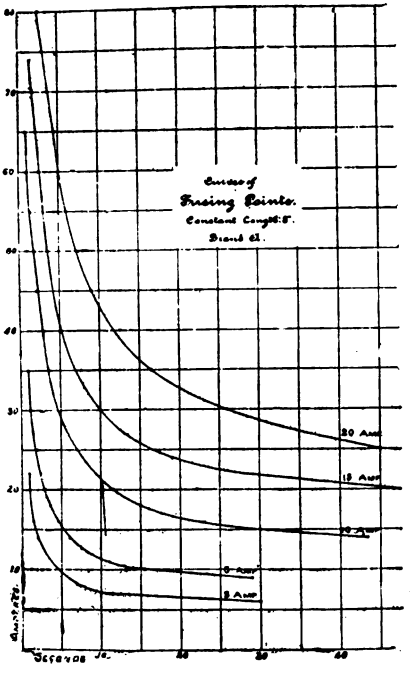

FIG. 3.

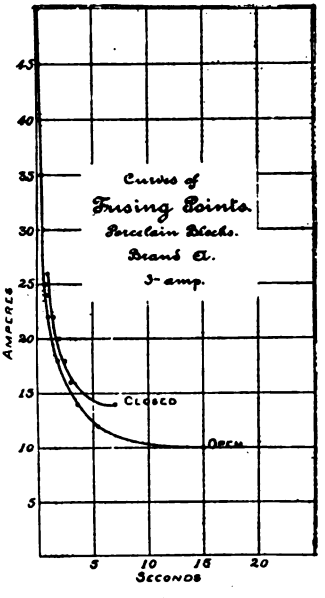

FIG. 2.

length, the block in all cases being horizontal. The supports practically prevented the breaking of the fuse from hydrostatic pressure. The results with A. and B. wires, and the German silver (18 per cent.), as well, are shown in Figs. 3–6. It was supposed though such curves are hyperbolic, that for abnormally high currents they would exhibit somewhat constant inertia times, due to the oxide coating and other mechanical causes. The results clearly confirmed this, the inertia time-constant in some cases amounting to two seconds.

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The blowing of the fuse is not immediately an electrical act. The current fuses the metal, the cross-section is reduced at some point due to gravity, unequal expansion, or "sweating"; the heat in consequence intensifies at this point, and a globule falls, breaking the circuit and establishing an arc, which soon burns out a length of the fuse. This accounts for the sluggish action of such thermal cut-outs. An ideal fuse would be one that would act at approximately a constant time interval for all currents in excess of its normal. It would, in this respect closely resemble the action of an electro-magnetic cut-out. Its curve would be a straight line extending from its normal point, and slightly approaching the vertical axis for all abnormal currents, being thus identical with the curve of the electro-magnetic cut-outs. In practice the curves of all thermal cut-outs must be more or less modified hyperbolas. The ideal curve could only be attained were it possible to eliminate conduction and radiation losses. This is evidently the line to follow in designing a sensitive fusing block.

The curves in Figs. 3 and 4 clearly exhibit the relative sensitiveness of small and large fuse wires, the smaller diameters approaching more nearly the ideal condition. This is of great practical interest in guarding against excessive currents of short duration, such as motors are subject to when operated from street railway, and power circuits. In such cases a multiple fuse of four pieces of 5-ampere wire would prove from two to three times as sensitive as one piece of 20-ampere size. Such multiple fuses have been found by the writer to effectually prevent the belt slipping off the pulley of small dynamos under short-circuits. The sluggishness of large fuse wires may be due to the cooling of the outer layers which, with the oxide coating, prevent the fuse from breaking. It is evident that this effect would be less in small wires. For this reason a thin ribbon should prove more sensitive than a round wire.

These tests with long lengths of wire reveal some actions which may account for the lowering of the fusing point by use. In the A wires, with a current just below the fusing value, the wires were found to "sweat"; the oxide film broke in places and allowed the molten interior to ooze out. When the current was shut off the globules were drawn in, leaving the wire pitted. With the B fuses the metal was found to be remarkably plastic and free from the oxide film. These fuses sagged badly and twisted, showing a high coefficient of expansion. As a result they were drawn out and the cross-section reduced.

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When used vertically, the metal flowed until a large globule formed, the rupture occurring just above this. In the case of

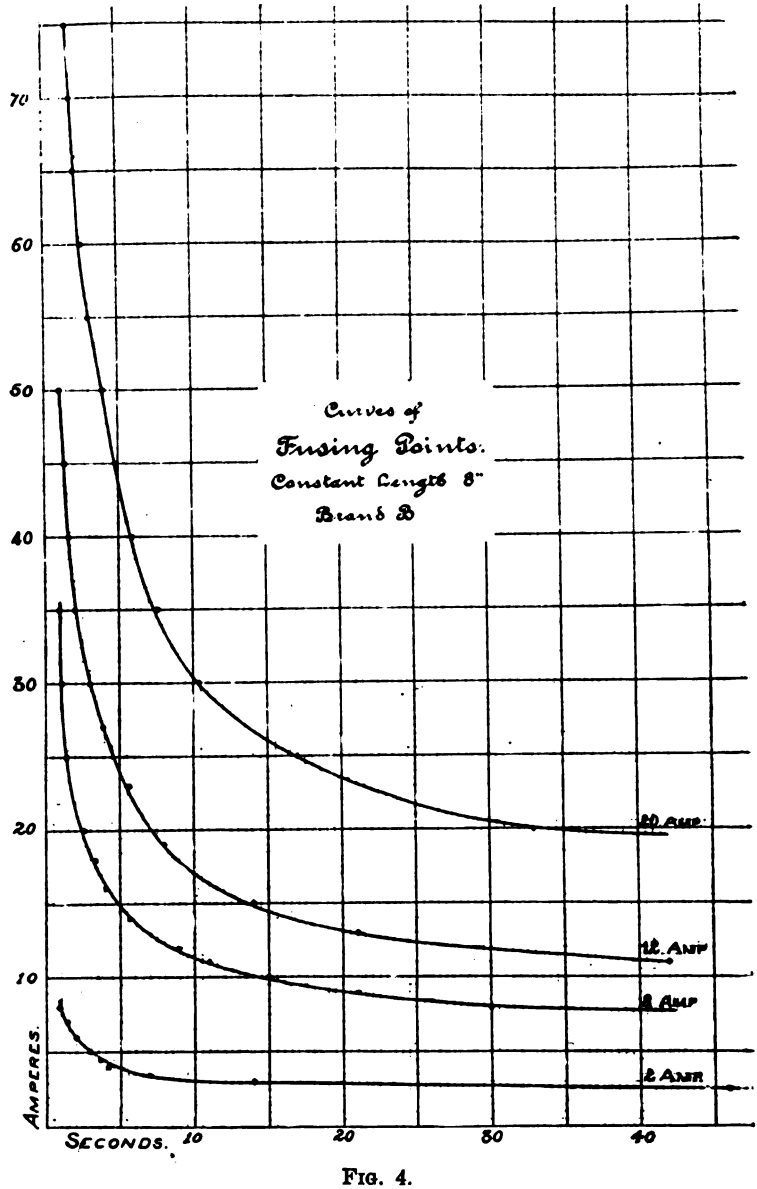

FIG. 4.

the German silver fuses, the sweating resulted in partially breaking up the alloy, the zinc seeming to melt out from the nickel

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and fusing with the copper, formed globules of brass. This was so marked that it would render such fuses too uncertain for use in all but the smallest diameters of wire.

A comparison of the 3-ampere curves in Figs. 2 and 3 shows the effect of shortening the fuse. The blowing current for 15 seconds of 6.3 amperes in the case of the short fuse in the open porcelain block, was raised to 10 amperes. Excepting the higher fusing points, the curve of the long fuse is the same as that for the shorter length. It is evident from such data that the usual

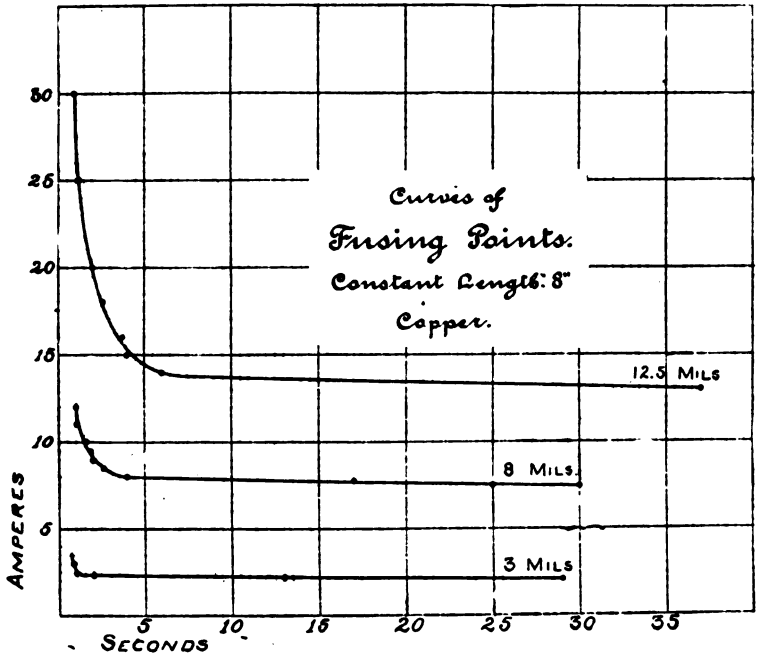

FIG. 5.

rating of fuse wires in ampere carrying capacity is practically valueless, and should be discontinued. The proper designation for such wires would be a table of carrying capacities for the lengths ordinarily employed.

The 10-ampere wire of Fig. 3 fused in 30 seconds at 15 amperes in an eight inch length; in a length of one-half inch in a covered block at 35 amperes, and in the open block, length seven-eighths inch, at 25 amperes. Accompanying each spool of the B wire was a stated carrying capacity for a given length, but this is not sufficient, since it furnishes no guide for other lengths.

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Copper fuses have frequently been stated to be more prompt in action than the alloys usually employed. Compare the curve of the 12.5 mil copper wire (Fig. 5) with that of the 12-ampere wire in Fig. 4, and the increased sensibility of the copper fuse is apparent. The plastic condition of the ordinary fuse alloys ex-

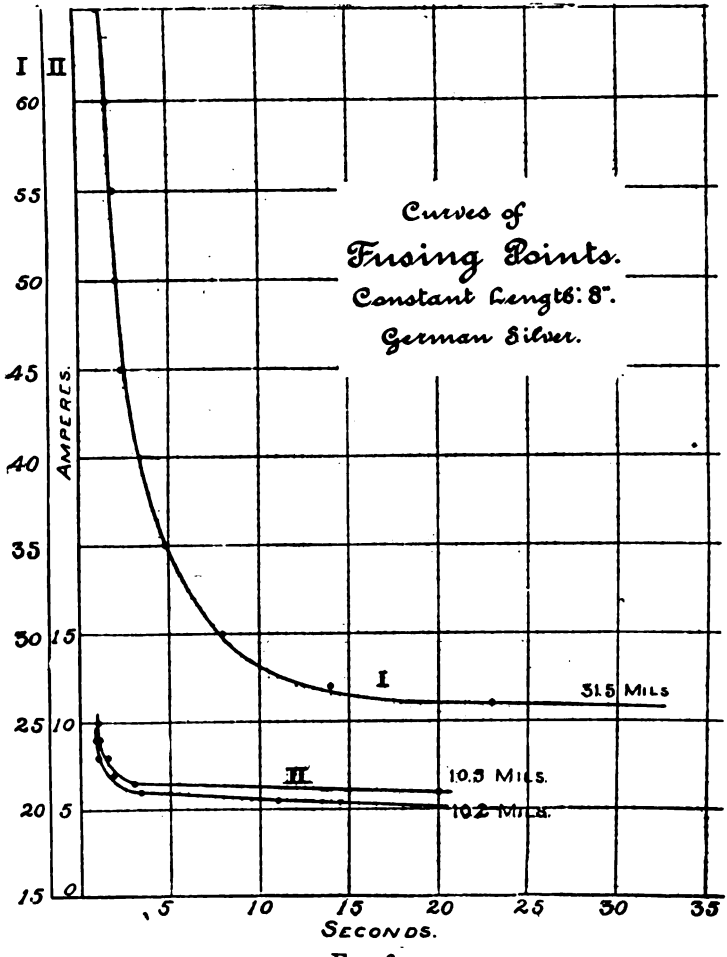

FIG. 6.

tends through a proportionately greater temperature range than the copper, resulting in a rounded curve. The copper fuses reached red and even white heat in these tests, while the other fuse wires scarcely reached a perceptible glow. This has a practical significance in selecting metals for fuse wires. Metals in

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general, which can be worked at or near a white heat, will prove most sensitive, since a slight increase of heat will make them highly fluid, and rupture will promptly occur. The practice of using copper in street railway circuits for limit fuses seems justifiable. Whether the oxide film of copper fuses would prove progressive in formation, is a question which has not been definitely settled. A 3-mil copper wire, which fused at 2.2 amperes in 13 seconds, was fatigued at a red heat for eight minutes;

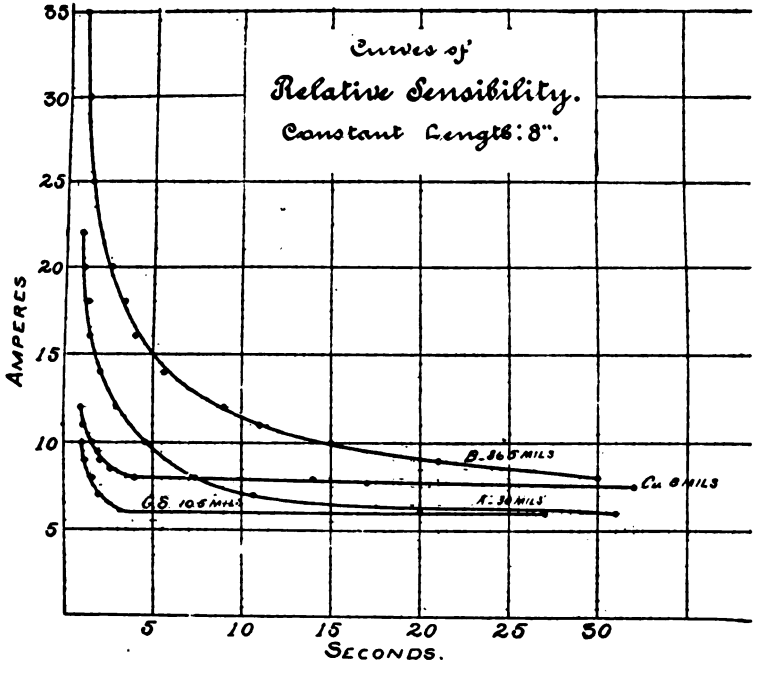

FIG. 7.

cooled and tested under the first condition, it fused at 2.2 amperes in 14 seconds.

The A fuses, cut from the ordinary lead-tin fuse wire, only worked at a bright red heat in very short lengths, such as ½ inch. This undoubtedly influenced the sharpness of the curve for the closed block in Fig. 2, and is a fact that seems to possess some practical importance. Our tests in general showed the desirability of working fuses at a red heat for normal maximum loads. But this is a question which must be eventually left with the underwriters.

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Fig. 7 gives the relative sensibility for the different fuse metals tested, and the copper curve is clearly the best. German silver acts well in these wires, but for the larger sizes (Fig. 6) it offers no advantages, and deteriorates more rapidly than any wire tested. It is now in general use on telephone and similar circuits. The wire is about four inches in length and inclosed in a fibre tube. A number of such fuses, obtained from the Chicago

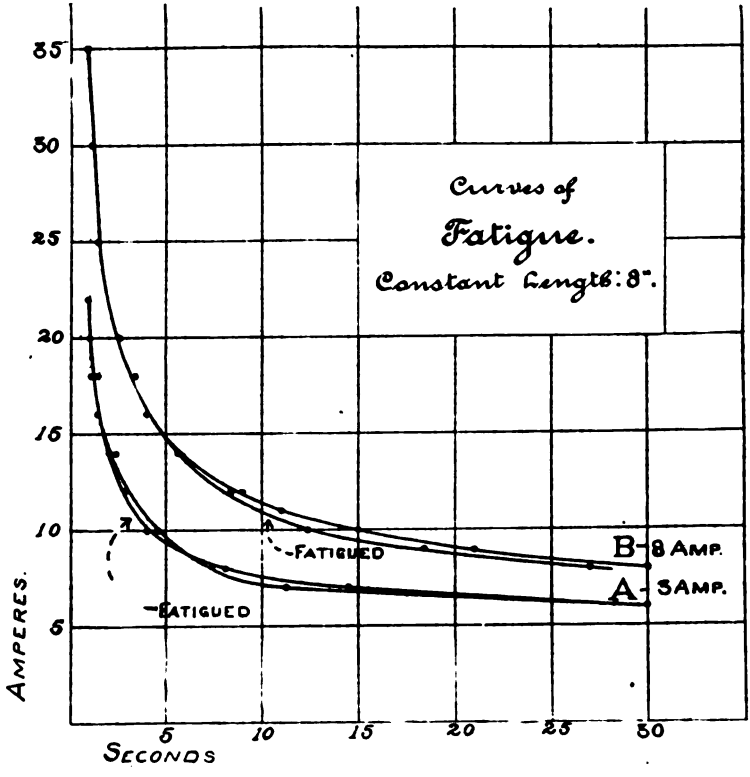

FIG. 8.

Telephone Company, were tested. They were rated for a carrying capacity of five amperes and fused in all cases within six amperes. A slight variation in fusing was no doubt due to the cooling effect of the tube in contact with the wire. Some such device as this, with copper wire for the fuse, would be most excellent for electric lighting and power circuits.

It was thought best to study the influence of "fatigue" on a wire. A special board was prepared with two rows of insulated

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pins placed ten inches apart. A length of fuse wire was threaded back and forth over these, the wire being supported out of contact with the board. A current, just short of the fusing strength, was passed for seven hours. The results are plotted in Fig. 8. It will be noticed that the A fuses experienced a positive fatigue, the B wire a negative one. This is of importance in practice, and shows the superiority of the B wire, whose fusing point was lowered while the other was raised, due to a diminution of cross-section and absence of oxide film.

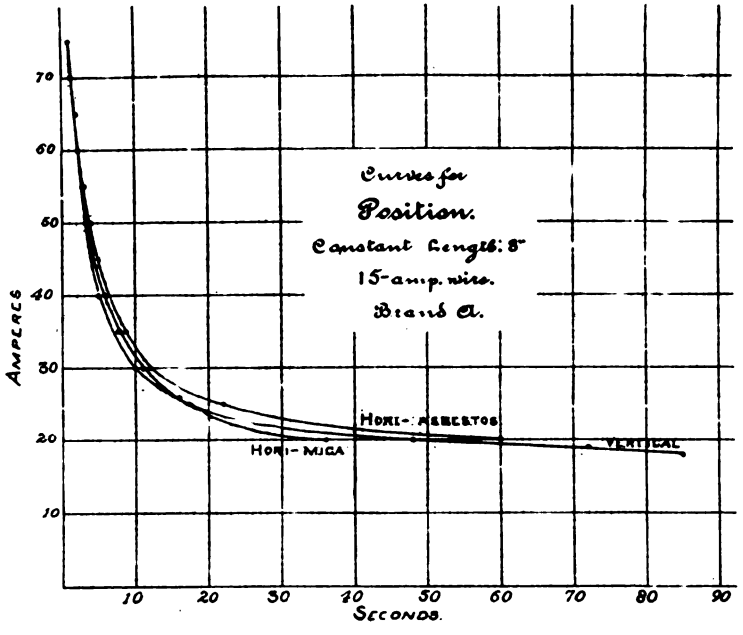

FIG. 9.

A great deal has been said about the influence of grease films on lead fuses. This point was also investigated. The grease was removed from the wires by immersion in KOH and NaOH with subsequent washing. In other cases the wire was cleaned by the use of fine sand-paper. The oxide film was also removed by immersion in nitric acid. Measurements showed that this treatment did not sensibly reduce the cross-section. When the oxide film was removed by either mechanical or chemical means it was noticed that a thicker coating formed at once, raising the fusing point. In short, these tests showed that nothing was

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gained by cleaning the wires, but that the thin film of grease deposited during the drawing of the wire was rather an advantage. The wires were also coated with shellac, but without encouraging results. Some coating, not affected by heat, and which would reduce the radiation, would doubtless increase the stability and sensibility of fuse wires.

For the following tests an adjustable fuse block was constructed, on which the fuse was held about one inch above the base, and

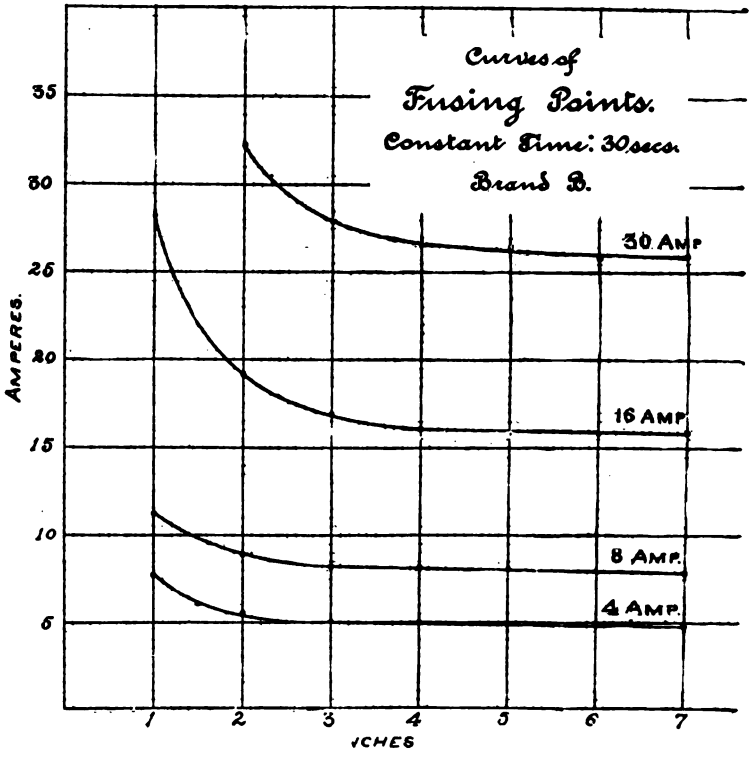

FIG. 10.

supported each inch by either thin asbestos or mica supports. In order to ascertain the influence of these supports, tests plotted in Fig. 9 were made. The influence of hydrostatic pressure is shown by the horizontal curve with the asbestos supports being higher than the vertical curve. The curve with mica supports is lower for the reason that the mica cut the softened wire.

A singular phenomenon was noticed with the A fuses blown horizontally in the eight-inch block. The arc would usually

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occur at about the same place near the center of the fuse, and when the time was within six seconds, the entire fuse was shattered into approximately equal lengths, varying from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch, depending upon the current employed. The length of these pieces varied inversely with the current strength. The uniformity of these results was noticeable throughout all our tests. The entire

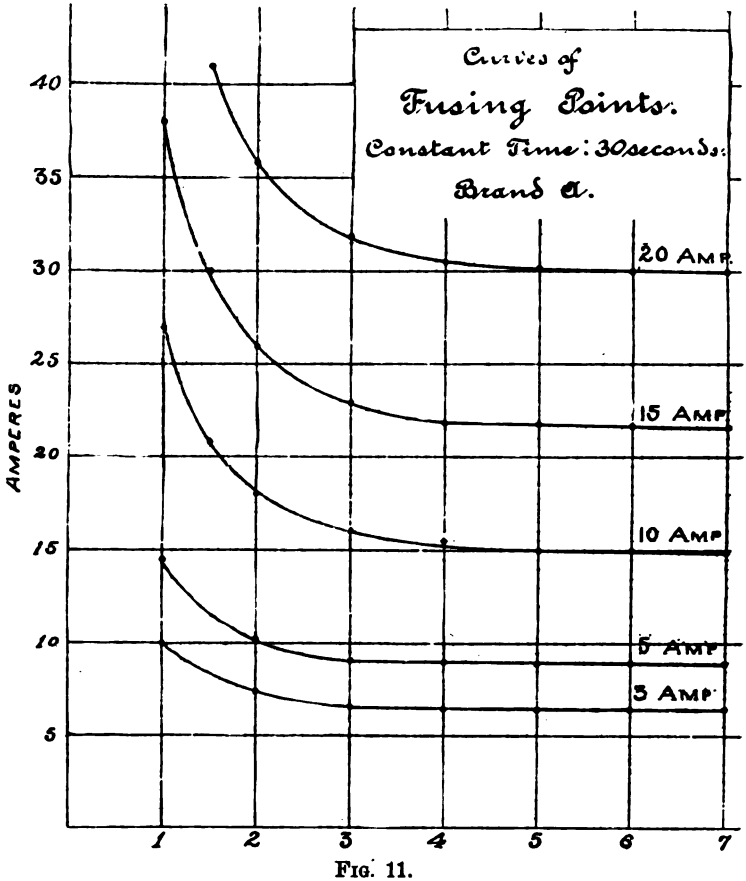

FIG. 11.

fuse, to within a short distance of the terminal, seemed to explode into fragments simultaneously with the formation of the arc. This rhythmic action has been pointed out by the author, for copper wire fused by lightning.[1] The ends of such pieces invariably showed a crystalline structure, indicating that the entire fuse was melted, and prevented from flowing by the oxide film.

1. *Electrical Engineer*, July 13, 1895, p. 38.

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So much seems to depend on the cooling effect of the terminals, that it was determined to work this point out with great care. The terminals of the adjustable block were made of brass, and purposely made unusually massive. Care was also exercised to keep the terminal-contacts bright and clean. Constant fusing times were adopted, with varying lengths. This method of experiment is extremely tedious, since it is not only difficult to ascertain the exact current for a length in a given time, but any

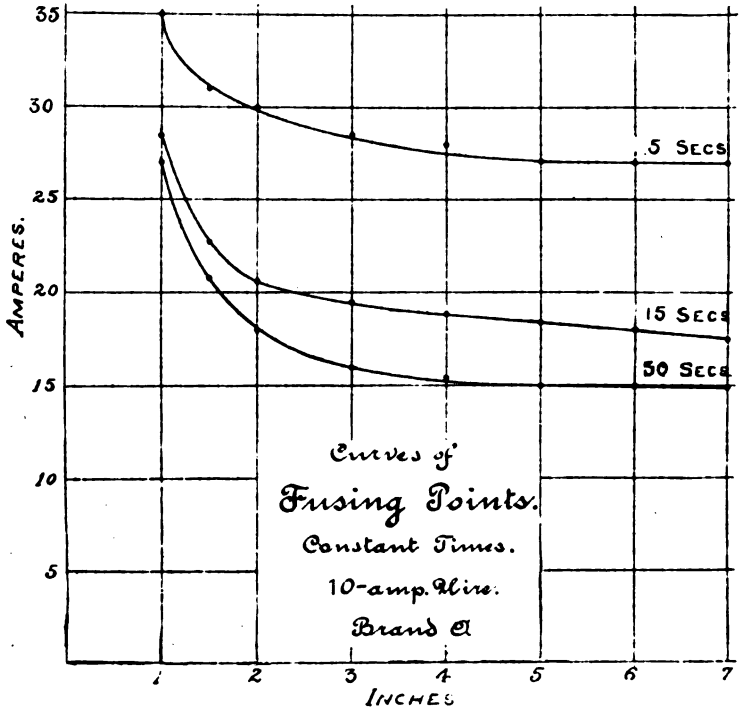

FIG. 12.

slight draught or variation in the current will produce a sensible modification in this time. Up to this point the current had been obtained from a 50-K. W. 110-volt D. C. dynamo, furnishing a sufficiently constant E.M.F. For the following tests a storage battery of 60, 180-ampere hour cells was employed. The result for a constant time of 30 seconds is shown in Figs. 10 and 11; and for constant times of 30, 15 and 5 seconds in Figs. 12 and 13. The relation between size of wire and length of fuse for maxi-

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mum sensibility is shown by the curves of Figs. 10 and 11. The curves of Fig. 13 exhibit well the sluggish action of the fuse wire. For five seconds two inches is the critical length, while for a time of 30 seconds it is nearly five inches. Data for times longer than 30 seconds are not materially different from those at this period. For a given fuse, then, blown in a given time, there

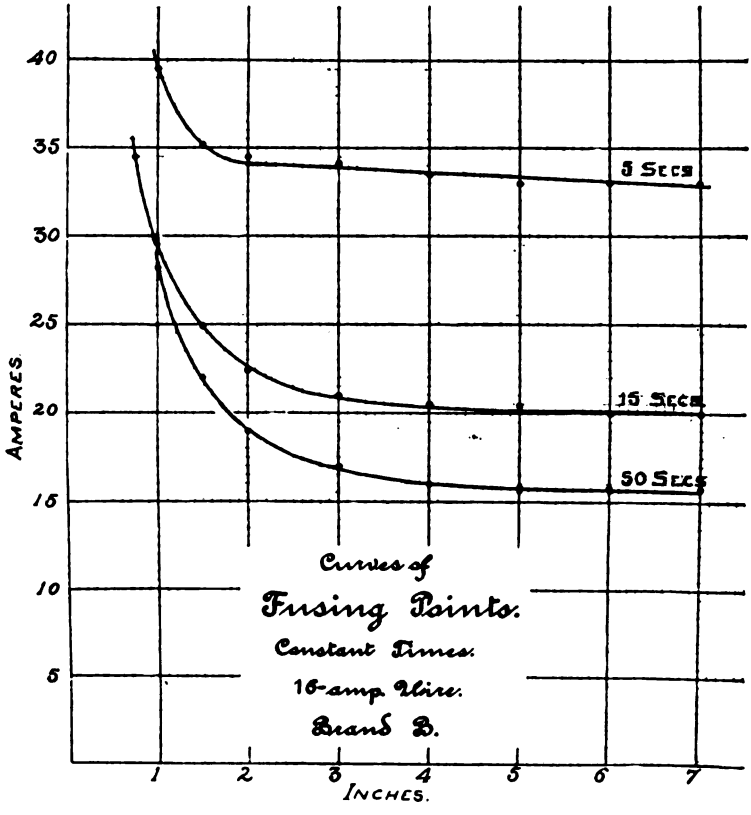

FIG. 13.

is a critical length. We are now in possession of full data for the complete discussion of this most important question.

If a fuse is to be employed for maximum sensibility at normal rating, the curves of Fig. 11 will enable the length to be determined by the location of the critical point in the curve, which is the point at which the cooling effect of the terminals becomes marked. For three- and five-ampere fuses, lengths of 2½ inches

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should be employed; the 10- and 15-ampere fuses indicate a length of 3½ inches, the 20-ampere of 4 inches. Judged of by common practice these lengths seem excessive, but the data clearly indicate where practice might be corrected.

Comparing the curves in Fig. 2 with these, it is readily seen that the effect of the terminals is equivalent to shortening the time as in Fig. 13, and so increasing the carrying capacity. But these short lengths in no case fuse normally. It is only adding the complexity of the fuse to the uncertainty of the contact. Should the fuse itself become oxidized, the carrying capacity will be largely augmented. We believe sufficient data has been presented to show that it is poor practice to employ short lengths to economize in porcelain.

We may now summarize some of the practical conclusions deduced:

1. Covered fuses are more sensitive than open ones.

2. Fuse wire should be rated for its carrying capacity for the ordinary lengths employed.

2. (*a*) When fusing a circuit, the distance between the terminals should be considered.

3. On important circuits, fuses should be frequently renewed.

4. The inertia of a fuse for high currents must be considered when protecting special devices.

5. Fuses should be operated under normal conditions to ensure certainty of results.

6. Fuses up to five amperes should be at least 1½ inches long, one-half inch to be added for each increment of five amperes capacity.

7. Round fuse wire should not be employed in excess of 30 amperes capacity. For higher currents flat ribbons exceeding four inches in length should be employed.

Armour Institute of Technology,
Chicago, Oct. 1st, 1895.

Discussion.

The Chairman:—This paper, while dealing with a question that is by no means new, and should long ago have ceased to be a subject of discussion, is nevertheless one which is more constantly discussed and no more settled, than many of the problems which are far more difficult inherently. The physical conditions governing the fusion of a wire would appear to be very definite and easily determined. Certainly no one would imagine that

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this subject would be one of the last to become definite from our point of view. But the fact remains that to-day fuse wires are by no means relied upon; indeed, the very term "fuse wire" is almost synonymous with unreliability. It certainly would not seem that this is a necessary condition. I think it is owing to the fact that the length of the wire, the terminals to which it is attached, and the question whether it is enclosed or open, and many other important conditions are entirely ignored. Under those circumstances no scientific accuracy can possibly be obtained. But provided each fuse wire were rated at a certain length and for use under certain conditions, I see no physical or other possibility of great variation between different fuses. Nevertheless the subject is so uncertain, and so many engineers express their lack of confidence in the whole matter, that it is well worthy of consideration. But it has already been discussed quite recently by the INSTITUTE at Niagara, and the point was there brought out, which I think should be borne in mind to-night, that we must know what our fuses are expected to do. In other words, if one engineer intends a fuse to accomplish a certain result and another engineer another result, it obviously cannot fulfil both expectations, and that is another cause of difficulty. Some require that the fuse shall carry an abnormal current for a certain small interval of time without fusing. Others require that it shall fuse instantly. No fuse, of course, can do both. But even that could be covered by having fuses of a certain "inertia" as Professor Stine calls it, and other fuses that are supposed to yield as soon as the current reaches a definite excess. The subject is certainly one that is worthy of discussion and is now open for consideration.

DR. EMERY:—Mr. Chairman: It is probable that the principal electricians of prominent companies have given these matters very close study in some cases, and in this connection I call attention to the fuse used on the railway motors of the Westinghouse company. If I recollect aright, they employ a fuse of No. 13 copper wire which is placed in a groove around a wooden block enclosed in a wood-lined box. Considerable length of fuse is thus secured, and it is protected from rapid radiation of heat. These fuses doubtless carry from 100 to 120 amperes and do not blow readily. One car will pull another on the track at a very slow speed and the fuse is rarely blown. When a fuse does blow it is with an explosion. I have used copper wire fuses frequently in experimenting with electric motors and found them very convenient and reliable.

MR. KENNELLY:—Mr. Chairman, the most important part of this important paper, is its end, where the conclusions appear, and I think, that at least in phraseology, if not in actual intention, some of these conclusions might be criticized; for example, the first conclusion, namely that covered fuses are more sensitive than open ones. Now I am not sure of the meaning that is intended

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for the word sensitive in this case. If the word sensitive means that the fuses will ultimately melt within narrower limits of current strength than if the fuses are uncovered, I suppose we would all agree that this is correct. But if the word sensitive means sensitive in regard to time, or in regard to range of variation in which the duration of the current is included, I think the very opposite is true—that such fuses when covered are not more sensitive. The reason, of course, is clear. If you surround a fuse with some solid substance, if you place it in contact with some solid material, so soon as you heat the fuse, the fuse commences to impart heat to the solid material, and it cannot attain a melting temperature until a fairly large amount of heat has been so communicated, so that a considerable time must elapse before the temperature of the neighboring material has been so far raised as will permit the fuse to melt at its normal current. On the other hand, of course a fuse that is protected from drafts of air, or a fuse that is even protected by solid materials is more apt to be true to its rating, than one which is liable to be influenced by all the air currents in the neighborhood. The difficulty with fuses, as we all know, and as the Chairman has expressed it, is the fact that no two men usually employ fuses for the same purpose. In some cases they are wanted to blow, and blow promptly the moment that their fusing current is exceeded. In other cases they are not wanted to blow until a large excess of current strength is reached, and the two requirements are so opposed that it is not remarkable there has been a great diversity of practice and rating. The only way to obtain a unity of expression and a unity of rating, is to state precisely how the fuse is to be used, and curiously enough these two papers, which seem to be so remote from each other in application, although bound up in the same pamphlet form, have a very important bearing one upon the other; because we find that the environment in the case of the annealing of hard armor plates is just the very condition which enables the enormous current density of 40,000 amperes to the square inch to be employed, when under ordinary circumstances only a small fraction of that intensity could be employed in copper at the same temperature. Very often you will find that a fuse melts far below its rated capacity, simply because the copper terminals are not sufficiently large to carry away the heat, and the lead is blamed for what is entirely the fault of the copper connections.

I do not quite agree with Dr. Emery that copper wires make the best fuses. It is often very convenient to use a copper wire for a fuse, but the difficulty with a copper wire is frequently that if you wish to employ a sensitive fuse that shall melt at only a small margin above its rated capacity, you must operate that copper wire red hot under normal conditions in order that it shall melt at a reasonably small percentage above normal, and I think that has been the principal objection to copper wire fuses up to the present time.

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Again, it surely is not necessary to employ fuses five inches in length, of five amperes on ordinary low circuits. If you can protect the fuse by putting it under cover, that is to say keep it from drafts of air and have specified or definite arrangements for clamping at the ends of it, you can use tin foil if necessary, for very weak currents, say below one ampere, and you can use fine wire for currents from one up to five amperes, without great difficulty. When you have various clamps and various conditions of air currents, then it is true that you must employ long fuses.

THE CHAIRMAN:—In the absence of the author I feel justified in making what appears to be an answer to Mr. Kennelly's first criticism in regard to Conclusion 1. As I understand him, he said that covered fuses signify those in contact with some material. I do not understand the sentence to mean that. It simply means enclosed fuses not necessarily in contact with, or perhaps not even within half an inch of any solid material.

MR. KENNELLY:—That would certainly overcome my objections.

MR. WOLCOTT:—I think that Conclusion 3 is quite an important one—that on important circuits fuses should be frequently renewed. If a fuse is run up to its rated capacity all the time, that certainly is very important. The metal will change, of course, that is shown in the paper here how the metal changes when the current is turned on. You certainly find that in ordinary fuses.

THE CHAIRMAN:—This matter is so fundamental in our profession that any progress that can be made with it is of considerable importance. It seems to me that the difficulty is largely dependent upon the fact that a certain spool of wire is sold as a ten-ampere fuse, without specifying under what conditions it shall be used. I think that is about the sum and substance of the difficulty. But there may be more to it than that, and if so, we should hear from those who know further.

MR. R. T. LOZIER:—I think one of the most important points that Professor Stine has called attention to is Conclusion 3, that is to say frequently renewing the fuses. I know when I was connected with the Edison company, that the oxidation of the fuses in the street circuit boxes was rectified by changing the alloy to overcome that objection. I know that in practical experience that point of changing the fuses is one that is seldom recognized. It is one that I did not know of myself. I think that that one fact alone is a very important one to the profession.

THE CHAIRMAN:—That point, however, would relate rather to the question of fuses blowing sooner than they should, instead of not blowing when they should. It is those which do not blow when they are expected to, that have given fuses the reputation of unreliability. It is the fuses which carry two and three and four times their normal current that electrical engineers are suspicious of, and not the fuses which blow too easily, although of course the latter is not desirable. A fuse should not blow

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below its rated current. At the same time it is not those which have given the bad reputation to fuses. I have heard hundreds of times of fuses carrying a multiple of the currents that they were intended for, and a large multiple at that.

MR. WOLCOTT:—I think the Chairman is entirely right in this matter. An instance of the trouble you generally find in fuses is this: If there is a fuse for a single light in the base of the lamp it sometimes will stand more than the plug that supplies the whole room, that is, the plug will blow and put out all the lights in the room instead of the single-light fuse blowing.

THE CHAIRMAN:—Of course in safety devices, on general principles, it is much better to have them act too soon than too late as, for example, a safety valve.

MR. WM. STANLEY:—I know very little of the subject, but it seems to me that a perfect fuse would be one having a variable temperature coefficient, and consisting of a substance whose resistance should remain practically constant for the lower working temperatures, and should increase rapidly with higher temperatures produced by abnormal currents. I think that a copper wire itself possesses a very decided advantage in one way over the ordinary fuse wire. The process of passing from the solid to the fluid state is, in all metals, when arranged as they must be for fuses, a gradual process, whether it is because of some outside physical condition or not I do not know, but I have often noticed that portions of a fuse, especially of a strip, would be quite liquid while other portions would still remain hard, when there did not seem to be any good reason for such inequality due to inequality of area. A copper wire passes from the solid to the liquid state with an explosion. The ordinary fuse wire droops and slowly explodes, if I may use such a term, and while I have found in using fuses on transformers that a copper wire is the most reliable, I have also found that it is well to enclose it if one wants very reliable work—wants the fuse to be quite accurate—to enclose it in a glass tube filled with sand or brick dust or any gritty insulating material. After the breaking of a fuse so enclosed, one cannot find the constituent parts of it at all. It is as though it had evaporated.

THE CHAIRMAN:—Points of that kind are just what we require, I imagine. My experience in regard to copper fuses has been that they are more reliable than the ordinary fuse wires, although some high authorities say that is wrong—that we should use easily fusible alloys, but as a matter of fact I think that all practical men who have to use fuses in emergencies would rather depend upon a copper wire that they know something about than on a fuse wire. Alloys are of indefinite composition, whereas copper wire is of very definite composition. In other words, it is almost perfectly pure copper. Alloys may consist of any proportion of almost any metal. That might account, I think, for many of the great variations which occur in practice.

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The idea of surrounding a copper wire with sand in a tube would seem to bring the conditions to a definite point, which is all, I think, that is needed. The conditions are certainly of the utmost simplicity, provided we can always get them the same. I cannot admit that this problem is a difficult one inherently. It is difficult only because on account of its extreme simplicity we have been careless about it and have not specified the conditions. We must specify how long the wire shall be, and where it must be placed, and, if necessary, we can have a dozen kinds of fuse wires of 10 amperes normal capacity to be used under different conditions. There is nothing very difficult about that or anything that differs very materially from the conditions in other questions. It is always necessary when we have definite scientific conditions to specify exactly what those conditions shall be, and that is what has been lacking in regard to fuses, and consequently their action has been a matter of guesswork and not of definite quantitative relations.

Dr. Emery:—Mr. Chairman: In line with the remarks of yourself and Mr. Stanley and in connection with my previous remarks, I call attention to the top of page 556 of the paper, which reads: "Copper fuses have frequently been stated to be more "prompt in action than the alloys usually employed. Comparing "the curve of 12.5 mil copper (Fig. 5) with that of the 12-ampere "wire in Fig. 4, and the increased sensibility of the copper fuse is "apparent." Examining the curve for copper referred to, it seems to be practically a straight and nearly horizontal line, and changes suddenly as the current is increased, whereas the diagram for the other fuse, curves through a considerable range. This seems to show very clearly that the use of copper for fuses is advantageous. It will be observed that Mr. Stanley's method of putting the fuse in sand, is in line with that previously mentioned of winding copper wire around a block of wood, as considerable length is obtained in that way and the wire is also protected from radiation of heat, with the additional advantage that it is non-arcing. The principle appears to be well established that the part of the fuse which it is expected will blow, should be protected from radiation and contact with materials that will carry away the heat rapidly. Just before a copper wire fuse blows, the fused metal gathers in drops with smaller connecting necks so as to look like beads on a string, and this action probably continues until the fuse is disrupted explosively.

Mr. J. W. Howell:—I do not know whether it is mentioned here or not, but one of the advantages of the copper fuse would be its rapid and known increase in resistance for temperature in which an alloy would be apt to be variable. I tried the experiment once of connecting a small piece of thin copper wire and German silver wire both the same size in series, and passing currents through them. With small currents the German silver wire would get much hotter than the copper, but as the current was increased, the increasing resistance of the copper made it very

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much hotter and it fused first, although the German silver was very much hotter at the start.

MR. KENNELLY:—The question of copper versus alloy is a very interesting one, but simply bears out the importance of defining what a fuse is intended to do, and the limiting range of overload at which it is intended to melt. In some cases when a fuse is inserted to protect a circuit of given normal maximum current strength, the fuse should not melt unless three times that current strength passes through it. In other cases the fuse should melt when the current strength reaches twenty-five per cent. above the normal. The fuses which will meet these two distinct requirements, are necessarily different.

Lead alloy fuses can be made which will melt at, or even below, the temperature of 100° C. Consequently, under definite conditions, such fuses may readily be made sensitive in regard to action at excess of current, for their normal working temperatures will be but little in excess of the temperature of the air.

Copper wire fuses, on the other hand, melt at say 1050° C, which is a comparatively high temperature. Even granting the existence of a larger temperature coefficient of resistivity, the wire will have to be maintained at a comparatively high temperature, by the normal current strength, if it is required to melt at a small overload. In point of fact the temperature coefficient of copper does not seem to differ greatly near red heat from its value at the boiling point of water, and in some cases it would be necessary to keep the wire at 500° C, or about red heat under working currents in order to effect fusion at a comparatively small excess of current.

When, however, a large range of current excess can be permitted, the advantage of copper in the directions pointed out by the Chairman and by Dr. Emery, are, of course, undeniable.

THE CHAIRMAN:—There is this to be said, however, that copper for a given resistance has a much smaller surface than any alloy of that sort; consequently its temperature might be higher, and still the waste of energy might be the same on account of its smaller radiating and converting surface. These alloys have rather a high specific resistance. Copper has a minimum specific resistance and would have the minimum surface. That, I think, would make up for considerable difference in temperature. It has also been pointed out that since copper has a very high temperature of fusion, the danger of setting wire to adjacent bodies is much greater when it does melt. But the low melting point alloys produce an arc when they blow, and furthermore any fuse should be wound.

MR. HOWELL:—Mr. Chairman, in practice, what fuses are called upon to go at a slight increase of current over their normal working current?

THE CHAIRMAN:—There are two classes of fuses, but if I were asked to give examples of fuses that are called upon to yield at a certain definite current, I would be puzzled to name them.

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MR. KENNELLY:—What I had in my mind was this: When you are working a motor, for example, there is a certain total amount of current that the machine will stand without injury, and when the current gets to that value you want a fuse that will certainly go. This limiting current strength may be two or three times the normal full load current strength. For such purposes a copper wire fuse may be suitable. But when you have a wire as, for example, a buried conductor with a sensitive insulating cover connected with a definite load of so many lamps for example, a comparatively small amount of current above the normal amount will heat that wire considerably, enough perhaps to damage the insulation, and you cannot afford to allow in such cases a very great range of current above the normal. There is a certain class of apparatus where you cannot allow very much range above the normal current. In telephony you have to put a delicate fuse in, arranged so as to just carry the normal current quite safely, but which with a little above that normal current will break. In such cases it seems to me a copper fuse is unsuitable owing to the necessity for operating it at a comparatively very high temperature under normal conditions.

DR. F. B. CROCKER:—(Vice-President Hamblet in the Chair.) As I seem to be taking the position of a debater rather than a presiding officer, I will ask Vice-President Hamblet to take the Chair because I cannot agree with Mr. Kennelly, and that would not be proper in a presiding officer. I fail in the first place to see any difference between a dynamo and a motor in that respect. Furthermore, I think that we are laboring under some misunderstanding in regard to what we mean in regard to overload. If we mean that the fuse will stand 25 per cent. increase for a few seconds, that is one question. If we mean that it shall not stand 25 per cent. increase for any appreciable time, that is another question. In other words, I understand Prof. Stine to mean when he speaks of inertia, that it takes an appreciable time for a fuse to give way even with an excessive current. Now I think that is a very desirable quality in a fuse—up to reasonable limits, of course. The motor, in that respect, is exactly like the fuse—in fact it is superior to the fuse. It will stand its overload for a greater length of time than the fuse will. The motor has a great capacity for heat since it contains a large weight of metal, but, of course, sparking is instantaneous in its effect; as soon as the excessive current occurs, if it be a direct current motor, it begins to spark. But it will stand that sparking a reasonable time without injury. I mean by reasonable time a few seconds. It will stand an excessive current for a few seconds without permanent injury, and that, of course, is the question which we are considering. So it seems to me that the fuse ought to coincide in its qualities and in its action with that which it is protecting, whatever that may be, and if this motor or whatever the device may be has a certain capacity for heat, and will stand this excessive

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current for a few seconds without injury, the fuse should stand it also, for it certainly is very inconvenient to have fuses give way with 25 or even 50 per cent. increase in current if that increase of current is momentary, because it has not injured the motor and there is no reason why it is an advantage to have the fuse blow. On the other hand I can see a great many advantages in not having it blow, provided the excessive current is only momentary. So I think that the quality of inertia is just what a fuse should possess in most cases, and I agree with Mr. Howell that it is difficult to think of any case where we do not want that inertia, because all the apparatus which we use, has, if anything, more inertia than the fuse. I can think of only one exception to that, and that is the Cardew voltmeter. I have been trying to think of a possible example since Mr. Howell asked that question. In that instrument we have a hot wire, but we don't want to have it get too hot, and it will only stand a definite current without permanent injury. It has practically no heat "inertia," and the little fuse which it has should go at a definite current, and should not allow any increase above a definite figure. But that is the only example that I can think of where a fuse should not have inertia because it is the only case where the apparatus which it protects has no inertia. In any case the fuse should agree with that which it protects.

Dr. Emery:—We all like to keep in view some simple rule based on experimental investigations, and in looking at the curves on page 555, Fig. 5, a very interesting relation is developed as to the proper size of copper wire to act as a fuse with definite amounts of current. It will be seen that approximately the amperes at the time the fuse blows are very nearly the same as the diameter of the wire in mils, showing that the resistance to fusion is proportioned to the radiating surface, as seems natural, and this is proportioned to the diameter. This simple rule may only apply to very small wires, as evidently the fuse used for railway motors above referred to, would not carry sufficient current if the rule applied to wires as large as those mentioned.

Mr. Stanley:—I might add just one word—it is this: That the use of sand in a tube containing a fuse wire, prevents arcing from the vapor of the metal. We are accustomed to put out an arc by blowing upon it and thus shattering it. In the case of the fuse surrounded by sand, the expansion of the gases due to the evaporation of the metal takes place through the spaces lying between the adjacent grains of sand, and the gases are shot through the sand and scattered in very much the same way as by blowing a breath of air across an arc. I have seen a fuse enclosed in sand which broke in carrying, I think, about 25 amperes at 4,000 volts, and which was not more than three or four inches in length.

[Adjourned.]

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Discussion at Chicago, October 23, 1895.

Mr. A. V. Abbott :—The paper that we have just listened to appears to me one of the most valuable contributions to the literature of "fuse wire," as it contains the first (so far as I am aware) attempt to make an accurate, comprehensive and systematic study of the behavior of fuse wires, with apparatus and investigators who were fully competent to the task undertaken, and I for one am exceedingly indebted to Professor Stine for the information thus placed before us. There is one point, however, upon which I am not quite clear. In the circuit described by Professor Stine, and in the records of experiments, I do not discover whether any allowance has been made for the time constants of the relays used for determining the minute intervals of time under consideration. It has been shown that intervals of time as small as $\frac{1}{1200}$ of a second are involved, and it appears to me quite probable that the time constant of the induction coil used would be of sufficient magnitude to introduce considerable error when applied to the measurement of time intervals as short as .001 of a second.

It is possible that no better means could be devised, or those which would be more accurate, but in consideration of results so carefully worked up, it appears that the time constant of the relay or induction coil might introduce a serious error in the results, and my question is therefore only as to whether any allowance was made for the possible introduction of errors of this description.

Prof. Stine :—We have considered this point very carefully, but if you will note the connections, it is evident that the currents actuating the relays have at all times such small values that this error is negligible.

Mr. Abbott :—Does not the relay require a sensible time to impress its record upon the paper after the actual depression of the key exciting the relay or the closing of the relay circuit, and is not this time a sensible fraction of the time which the relay is supposed to measure and record?

Prof. Stine :—There is undoubtedly a time lag in the action of the relays. Those were adjusted to as short range of armature movement as possible. The actual value of the time lag was of no consequence, providing the relays were adjusted to equal time lag. This adjustment was made as accurately as possible, thus rendering the relative time intervals extremely accurate. The time intervals were those showing the actual time of the throw of the switch and the blowing of the fuse.

Mr. Abbott :—A still more important point is the bearing of the length of the fuse upon the disrupting current. I am not quite clear as to whether the experiments described indicate that after a certain length of fuse is reached, little or no variation in carrying capacity is observed. The disruption in the fuse is

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caused by raising the temperature of the metal composing it, to such a point as will melt it. The necessary heat is obtained from the energy developed in the fuse by the current. In any given time, the amount of heat contributed to the fuse is proportional to the square of the current and the resistance of the fuse wire. There are three causes of dissipation of heat:

First: Radiation which is due to the amount of radiating surface presented by the fuse wire.

Second: The heat lost by conduction to the terminals of the fuse, and there dissipated.

Third: The amount of heat absorbed in raising the temperature of the fuse wire and in melting it.

I have always had the idea that if the length of fuse was so great that the amount of heat lost by conduction to terminals was an insensible fraction of the heat delivered to the fuse by the current, no further increase of length would vary the carrying capacity of the fuse. In examining the curves illustrating the paper, it appeared that these curves indicated an approach to this condition, but from the fact that the lines did not become parallel to the axis, indicated that this principle was not carried out to such an extent as I had previously imagined to be the case.

Now, one other point: Are there any curves which went into that point particularly? That is to say, the ratio of the length of the fuse to its carrying capacity and the time?

PROF. STINE:—Such a curve was platted, and an approximate equation derived therefrom. Further investigations seemed desirable, and for this reason it has been withheld. We hope to give our results in an early communication.

MR. ABBOTT:—I have always felt that the emphasis of experimental evidence should be directed to convincing the people of the advisability of using long fuse blocks, thereby contributing to the reliability of such protecting devices. I would also like to ask why it was that no experiments were carried on for higher currents than those which are shown. A greater proportion of the work seems to have dealt with currents of 40 amperes or under, while there are only one or two instances of the employment of 60 or 80 amperes. It would be interesting to know something of the value of the length of the fuse in its relation to currents of considerable magnitude, such as would be found upon our larger street railway circuits, and also the effect of alternating currents.

MR. LUDWIG GUTMANN:—I would like to know from Prof. Stine whether other experiments were made showing the proper rating under heat conduction. Would it not be better to make fuses of such lengths that they could be rated with conduction present, and thus raise their sensitiveness? If the same fuse may be rated higher when covered, would not this be better?

PROF. STINE:—I think that this point is clearly emphasized in paper. We have advised just the opposite procedure. It is

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difficult to rate the value of condition, owing to variations of contact and the character of the contact surface. It seems better to use a fuse under such conditions that its blowing point shall be normally that of the fuse itself.

MR. ABBOTT:—Prof. Stine shows that in all cases there is an apparent interval of one or two seconds in all fuses, no matter what the current is before the fuse ruptures.

It appears from these experiments that no matter what the size of the fuse, or how large the current, there is an appreciable interval of time in which the smallest fuse might carry almost an infinite current.

PROF. STINE:—I think the maximum current employed was 110 amperes. The time lag was $\frac{348}{1000}$ of a second for everything above 40 amperes, and for three ampere fuses the time lag was $\frac{148}{1000}$ of a second.

MR. ABBOTT:—From the care exercised in the experiments and the reliability of the apparatus used, it appears that we can certainly trust the time readings to .001 of a second, or thereabouts.

The experiments show that there is a sensible interval of time amounting to from one to three seconds, during which the fuse does not fail, no matter how large the current is to which it is exposed. It would be interesting to know to what extent this increase of current for the first few intervals of time could be carried. It seems quite certain that if a small fuse were exposed to a large current of some thousands of amperes, an enormous amount of heat would be given to the fuse, and it is a pertinent question as to *what* becomes of this heat, and *why* it is that the fuse does not fail more promptly.

MR. LOUIS PRIVAT:—When an arc occurred on blowing the fuse, did you note whether the arc was sustained?

PROF. STINE:—We photographed an arc in a number of cases. Would that answer your question?

MR. PRIVAT:—Yes, partially. What I wished to get at was the destructive character of the arc. What is sufficient to cause a fire risk?

PROF. STINE:—That is a question we did not investigate, since we found the rupture of fuse to be quite uniform. One can scarcely speak of a sustained arc in the rupture of the fuse wire itself. The arc occurs only when the rminals of the fuse-block are too near together.

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LOCAL ANNEALING OF HARD-FACED ARMOR PLATES.

A meeting of the Western members was held in room 1737 Monadnock Block. Mr. C. C. Haskins was elected chairman for the evening. The paper by Mr. Lemp (see page 529) was read by Mr. George Cutter, in the absence of the author. Following the discussion, a paper on "The Rating and Behavior of Fuse Wires," (see page 546), was read by the author, Professor W. M. Stine.

Discussion at Chicago, October 23, 1895.

Mr. Arthur V. Abbott:—The subject of annealing armor plates, as presented this evening, I think opens quite a broad field in the special use of local heating by means of electric current. While the particular application here instanced, that of annealing armor plates, is probably one which would be more useful to the various governments of the world than to commercial enterprises, yet the application of this method of local annealing will be advantageous to all who deal with surfaces of iron and steel. For example, I have known of instances where unequal chilling of the ring forming the tires for locomotive wheels has resulted in loss of the forging, owing to there being no means of locally changing the hardness of the metal at the chilled points. If by some means, such as the method set forth in the paper this evening, we can effect local annealing without injuring the rest of the material, or changing its characteristics, it appears that the process could obtain an extensive application in the various branches of steel manufacture. Such a process would seem to be particularly advantageous in the manufacturing of steel rolls and other forms of steel castings.

Mr. Samuel Rodman, Jr.:—The paper which has just been read is particularly interesting and instructive. I do not know that I have much to add to what Mr. Abbott has said on the subject except in regard to one point, and that is in using this annealing process, we must confine ourselves to those materials

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which have a fugitive temper. In the case of certain materials, such as chilled iron, the hardness is permanent, a characteristic brought about by the sudden cooling of the molten metal as it comes in contact with the chill molds in which it is cast. If the rolls be made of steel, I should think, as Mr. Abbott suggests, that the electrical annealing process would be very valuable in rendering uniform the hardness in various portions, but the metal known as "gun metal" (which, chilled, is used in Germany, and probably will be in this country, for sea-coast fortifications, weight not entering as much of a factor as it does in the armor of war-vessels), would not be susceptible to this annealing process.

One other feature in this paper to-night has attracted my attention, viz., the applicability of this process to the construction of burglar-proof safes, a business with which I am somewhat familiar, though more in the sense of destruction than of construction.

Ordinary or laminated safes as usually constructed are made of plates of steel bolted together. The structure is first set up when the plates are soft and the bolt holes made, always a little larger than the bolts which are to be put into them. This is necessary in order to allow for certain warping and twisting in the plates which invariably takes place in the tempering process. The structure is then taken apart and the plates tempered, and finally put together making the finished article. The result, owing to the necessarily uneven warping and twisting, is a very ricketty and unreliable affair, and I should think the process described in the paper to-night would be very valuable in connection with such structures, if it can be applied to approximately thin plates, say one-half inch or one inch, of hardened steel.

Mr. Abbott:—I referred to the use of rolls made of steel castings. The use of the chilled iron roll is disappearing.

Iron rolls are valuable as having a surface hardness which is not obtained perhaps in any other metal. On the other hand, they lack the wearing quality and the strength of those made from steel. The makers of steel castings have experienced great difficulty in obtaining the necessary uniformity. It is very difficult to pour a large steel casting which can be machined all over without discovering hard or soft spots. When the surface of the metal is unequally hard, uniformity in machine work cannot be attained, as the tool will cut more deeply in the soft spots and less in the hard ones. Thus, not unfrequently, castings are lost, from the impracticability to machine them with sufficient accuracy. It appears to me that such cases could be treated by local annealing.

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BRADLEY ON PHASING TRANSFORMERS.

Discussion at Chicago, Sept. 25th, 1895.

[See pp. 505 and 518 *ante*.]

Mr. A. V. Abbott:—The subject this evening is of great interest, especially to those who are particularly interested in the electrical transmission of energy. When the continuous current first came into use we thought the problem was solved, but presently we found that the transmission was limited, owing to the fact that we could not build generators and motors to carry sufficiently high voltages to make the cost of conductors come within commercial limitations, resulting in the development of the alternating system. But presently it was found that the plain alternating system was practically confined, in its usefulness, to lighting work, as power distribution was not altogether a success. The polyphase system was then considered, and it was found that it was impracticable to give consumers all the power they needed on variable loads, and since then there has been a constant effort to find something that would combine the advantages of all the systems. If it shall ever be found practical to obtain a transformer which shall give us different phases from the same generator, there will be little more to be asked.

Mr. Fred. S. Hunting:—It seems to me that this is a most novel invention, and one which bids fair to be of great practical importance and to show excellent results. Every engineer knows that to-day there is very much more money invested in single-phase high period apparatus in central stations in this country than in any other incandescent lighting apparatus. Most, if not all of it, is very well adapted for incandescent lighting, and thus far serves its purpose, but it would be a great financial loss if these systems were to be displaced by a polyphase system capable of operating both lights and motors. Many stations could increase their earning capacity 50 per cent. or more, if they could furnish and operate motors from their present machines, and that without increasing probably anything but the fuel expense. In

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view of the enormous investment in single-phase plants, it is almost imperative that we should have reliable and efficient motors for that system which will start with a powerful torque. Many of us have worked at this problem, and I am pleased to note the success Mr. Bradley has met with in this direction, and that it is not a mere paper and pencil or mathematical success. There is no simpler, more reliable (if well built) or efficient motor than the polyphase motor, and the combination of this motor with the existing single-phase systems is, indeed, a most fortunate invention. The invention of a successful and practical phase splitting or phasing, transformer at once puts the single-phase system on an even or more than even footing, because of its simplicity, with the polyphase system for the distribution of both light and power. With a phasing transformer it is at once possible to obtain from the single-phase systems any number of phase currents that may be required by any motor. The constancy of the phase difference in the currents delivered by this transformer is, of course, vital to its practical utility, and the motor, no doubt, helps to steady the phases. It is interesting to note how perfectly steady this phase difference is in the transformer described. Any one who has stopped to study the induction motor will realize, and if he has built them, will realize still more, how difficult it is, especially in the smaller sizes, to keep the magnetizing or idle current in them down. With a large number of small motors, which would be what many plants would have, the idle current would become a serious question. In this transformer it is possible to have the condenser serve the double purpose of assisting in the phase changing, and in largely eliminating the idle currents. It is, it seems to me, very fortunate that with this construction you have a leading current at full load, and a lagging current at no load, because it brings the point of either lag or load more nearly the average working load point of the motor. I have no doubt if desirable, that the full load current could, by proper proportioning of the apparatus, be caused to lead more yet. I regret that Mr. Bradley has not given us some actual figures in the way of an actual test, but this, no doubt, we may look for later. Condensers are destined, I believe, to come into very general use in connection with induction motors in order to take care of idle currents. A cheap, compact and reliable condenser will be the first requisite; and it certainly seems, from Mr. Bradley's paper, that he has succeeded in building one that should be very reliable and is very compact. I hope that at some time in the near future we may learn more about this condenser. The compactness will depend upon the E. M. F. that it can be worked on and be reliable, being more compact as the voltage used becomes higher. It is certainly an advantage both as regards the condenser and the motor, to be able to locate the condenser on the primary and use a comparatively low voltage on the motor. I am glad that we have an opportunity to see the motor in actual

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service, and that Mr. Bradley has seen fit to so demonstrate what the apparatus will do, instead of resorting to numberless mathematical equations. If Mr. Bradley will next give us a period changing transformer without moving parts, I am sure his plans for long distance or short distance railroad work for that matter would take on a genuine Western boom.

MR. ABBOTT:—To what extent would the condenser be affected by lightning? While condensers can be made solid pieces of apparatus, they become exceedingly expensive ones when made to stand very high voltage. Condensers will be frequently subjected to atmospheric changes from which lightning arresters would not protect them. It is practically impossible to use a liquid condenser on the primary.

MR. W. S. HULSE:—Oil condensers have been tried, but up to the present time their results have not been altogether satisfactory. The effect of lightning, should it enter the transformer, would probably be to burn out the condenser or coils, and, perhaps both; placing it, in this respect, on a par with any transformer. However, for lack of experience which can only be obtained from the every day operation of the system, I can not tell what precautions would be taken to modify this danger should the ordinary means fail.

PROF. STINE:—Of course, the whole question of any form of distribution of this kind comes to the total cost. Here is an apparatus which is somewhat more complicated than we are accustomed to employ. The question arises as to what the cost of the same will be, and what the cost of its idle load will be. During the time that the combined system is in service, would it take more watts than the ordinary system? Is its cost likely to be greater than the cost of other systems which require perhaps a larger amount of copper in the line, owing to the necessity of more wires or other things of that sort, and will it be likely to be a question of serious moment? Are there any facts bearing upon this point? The magnetizing current or the current which the transformer is taking from the line when the motor is cut off, is very small, and no greater than that of an ordinary transformer of its capacity. This feature indicates a close similarity to any transformer system in respect to no load currents. As described in the paper, the condenser seems to keep from the line the idle currents found in the motor, and thereby gives the system a very high power factor. This feature reduces the cost of the line to a minimum, as compared with systems where the idle currents reach them—where they can only be provided for by larger amount of copper and, therefore, additional cost. A glance at the motor shows that it is very cheap to build. I suppose that reference is made to the first cost of transformer. There is no reason why the cost cannot be brought down to equal that of two small transformers whose added capacity will equal that of the motor or thereabout. The cost of the condenser will, of course,

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be additional, as it is not included in the reference, and no figures can be given on it at present.

MR. BION J. ARNOLD:—I would like to see this system tried in electrical railway work. I have been hoping for something of the kind for sometime, and now we have reason to expect a trial of it some time in the near future. As yet, however, we have no results that we can depend upon. It is not yet in a state that would warrant any railway company taking hold of it. The principal objection to the operation of this system, as outlined here, for electric railway work, would be the bringing of the high voltage current in immediate contact with the car. The opposition which this would meet with from all sources, in carrying this voltage so near the passengers would be severe, but possibly this opposition may be eliminated, as the opposition to the practice of carrying 500 volts has been overcome. One other objection will be found. owing to the fact that an induction motor can be overloaded and stopped easier than a direct current motor, thus making it necessary to carry larger motors on the cars in order to meet the maximum demands of the car, and if we are compelled to carry a larger motor we must work it below its capacity, and probably at an inefficient rate. I should like to know more regarding the efficiency of the motor at various loads.

MR. HULSE:—It would be very difficult to state in figures the efficiency of such a system before the apparatus has been completed in its various sizes, but there is no reason why it should not equal that obtained from any well-designed three-phase motor under load, since it actually operates as such. In multiphase motors, when they are rated from one-half to three-fourths their actual breaking down capacity, it is quite possible to establish this point on its various characteristics, so that the motor is most efficient there, and the same is true for motors on this system. At light loads the efficiency should compare with that of any three-phase motor operating from a three-phase generator, at least there is no evidence to the contrary.

MR. ABBOTT:—The question of efficiency, however, would come in pretty seriously. There is no doubt but that the induction motor is as good, on the whole, in that direction as we could have. I certainly agree with Mr. Arnold's question as to the propriety of operating trolley lines at high voltages, and that brings up the question whether or not it would be practical to divide the railway lines into sections.

MR. HUNTING:—On any line it would be necessary to use a very much higher E. M. F. than you could carry on your trolley, even 1,000 volts, and we might even raise that, after a time, to 2,000 volts. The feeder lines could be carried on at any voltage up to 10,000 volts, varying with the length of the line.

PROF. STINE:—At this point the problem assumes a phase which seems to be giving the railway people some little uneasiness. The method of furnishing power, especially for freight hand-

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ling, introduces the serious problem of dividing the sections evenly. The railway problem, if solved, I think will be solved on this line. Taking up Mr. Hunting's suggestion, these sections, or the second primaries, would occupy long stretches. The difficulty would arise from the distribution of the train loads. I recognize in this a means of using high primaries, and so you would have your whole equipment complete. You would have no idle transforming devices. It seems that in the change from steam to electricity, the capital invested in idle transformers for trains averaging from 2,000 to 5,000 horse-power would be saved. I want to express my delight at seeing this arrangement here this evening. I wish we could take up the suggestion of a period-splitter. I am not aware of any method known to physics by which you could split the period of a single phase. You can modify the system so that you can change the period, but given a single-phase system, there seems to be no way of splitting it. I would like to ask Mr. Hulse about this transformer. Most systems which have been adopted have found the condenser a source of weakness and expense to maintain, and have introduced a number of complications.

Mr. Hulse:—The condenser occupies a space of a cube about four inches on a side, or about 64 cubic inches, including case and accessories. It was pointed out in the paper as well as indicated by the curves, that the impressed electro-motive force used in the tests was of sine form, and from them the operation of transformer and motor on complex wave forms could not be predetermined. Since the writing of the paper the transformer and motor have been operated very successfully on the Wood alternator, which, being ironclad, possesses a peaked complex wave form. It has been running before you under load on a current supplied by a small Westinghouse machine, and I think its successful operation is well established. In no case has it been found necessary to alter the adjustment in the transformer.

Mr. Arnold:—We have all been very much instructed and interested with the paper read here to-night. I am sure that I, for one, appreciate it, and move that a vote of thanks be extended to Mr. Bradley, as well as Messrs. Hulse and Hunting, for the paper, and for the pains they have taken to display this apparatus to us.

Mr. L. L. Summers:—I wish to second Mr. Arnold's motion, and would like to add that I have the highest admiration for the forms of motor he has shown us this evening.

Mr. Abbott:—Let us hope that these experiments will be continued in the near future, and that we shall shortly have the pleasure and benefit of some further information along the same lines.

Mr. Hulse:—I would like to thank Prof. Stine for rendering us his valuable assistance in setting up this little apparatus.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, November 20th, 1895.

The 101st meeting of the INSTITUTE was held this date, at 12 West 31st Street, and was called to order by President Duncan at 8:05 P. M.

Mr. W. J. Hammer, Secretary *pro tem.*, read the following names of associate members elected and transferred at the meeting of Council in the afternoon.

Name.	Address	Endorsed by.
BALL, WM. D.	Consulting Electrical Engineer, Ball & Allen, 1625 Monadnock Block, Chicago, Ill.	L. K. Comstock. W. M. Stine. A. S. Hibbard.
BERG, ESKIL	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Chas. P. Steinmetz. E. J. Berg. Wm. G. Ely, Jr.
BROWN, CHAS. L.	Student at Cornell University. Residence, 6422 Drexel Ave., Chicago, Ill.	Harris J. Ryan. Ernest Merritt. E. L. Nichols.
BURR, CLINTON C.	Electrical Engineer, Pittsburg Reduction Co., 701 Ferguson Block, Pittsburg, Pa.	Chas. P. Steinmetz. Ernest J. Berg. H. G. Reist.
BURTON, PAUL G.	Constructing Electrician, Western Electric Co., residence, 45 W.127th St.,New York City.	G. A. Hamilton. C. O. Mailloux. H. F. Albright.
DU BOIS, JULIAN	Chief Electrician, Mohawk Division N. Y. C. & H. R. R. R. Albany, N. Y.	A. E. Wiener. R. J. Pratt. Arthur Churchill.
FRIEDLAENDER, EUGENE	Electrician, Carnegie Steel Co., Duquesne, Pa.	Joseph Wetzler. P. A. Lange. L. A. Osborne.
GOTT, CLARENCE P.	Chief Engineer and Electrician Grand Central Palace., residence, 83 Washington Place, New York City.	N. W. Perry. Wm. A. Rosenbaum. J. Elliott Smith.
HOPKINS, NEVIL MONROE	Scientific Literature. 1730 I Street, Washington, W. C.	Chas. A. Stone. H. M. Whitney. F. S. Pearson.

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HUBBARD, ALBERT S.	Electrician, Alexander-Chamberlain Electric Co. Residence, 305 E. 34th St., New York City.	Harry Alexander. F. C. Bates. Townsend Wolcott.
MACCOUN, ELLICOTT	Ass't Supt. of the Electrical Dept. The Carnegie Steel Co., Munhall, Pa.	Wm. J. Hammer. H. S. Hering. Thos. Duncan.
PHISTERER, FRED'K WILLIAM	Graduate Student, Cornell University, residence, 84 Heustis St., Ithaca, N. Y,	Harris J. Ryan. E. L. Nichols. Fred'k Bedell.
RATHENAU, ERICH	Electrical Engineer, Allg. Electricitats Gesellschaft, Berlin, Germany.	W. D. Weaver. Cecil P. Poole. R. W. Pope.
WARREN, ALDRED K.	Proprietor, A. K. Warren & Co., 465 Greenwich St., N. Y., residence, New Brighton, S.I., N.Y.	R. T. Lozier. J. C. Bennett. W. G. Whitmore.
WEBB, HENRY STORRS	Instructor in Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Alex. Macfarlane. W. H. Powell. J. H. Klinck.

Total, 15.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, Oct. 11th, 1895.

HARTWELL, ARTHUR,	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburg. Pa.
MARTIN, JULIUS,	Master Electrician, Equipment Dep't, New York Navy Yard.
STEARNS, JOEL W., JR,	Treasurer, Mountain Electric Co.. Denver, Col.
OUDIN, MAURICE	Electrical Engineer, General Electric Co., Schenectady, N. Y.
COMSTOCK, LOUIS K.,	Electrical Engineer, Monadnock Bld'g, Chicago, Ill.
BROWN, EDWARD D.,	General Inspector, American Telephone and Telegraph Co., New York City.
LA ROCHE, FRED A.	Vice-President and General Manager. New York Electric Equipment Co., New York City.

O'CONNELL, J. J., Telephone Engineer, Chicago Telephone Co., Chicago, Ill.

DARLINGTON, FREDERICK WILLIAM, Consulting Electrical and Mechanical Engineer, Philadelphia, Pa.

HENSHAW, FREDERICK VALDEMAR, Electrical Engineer, Providence, R. I.

Total, 10.

THE PRESIDENT:—The subject this evening, gentlemen, is "Storage Battery Applications." It is remembered, of course, that this is a discussion, and the publication of remarks made is under the rules which govern the publication of discussions; that is, the matter is to be gone over by the Editing Committee.

Several gentlemen have been kind enough to send preliminary reports of what they are going to say, and I would call on Mr. A. E. Childs for the first statement to-night. In Mr. Childs' bsence, I would ask Mr. Wolcott to read his communication.

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Communications presented at the 101st Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 20, 1895.

STORAGE BATTERY APPLICATIONS.

(A Topical Discussion.)

COMMUNICATION BY ARTHUR E. CHILDS ON "THE STORAGE BATTERY FOR CENTRAL STATIONS."

The object of this communication is to bring before the INSTITUTE the main facts and considerations concerning the application of accumulators in electric generating stations both for light and power. The fact that storage batteries have reached a point of high efficiency and low cost of maintenance, has stirred up engineers in this country to consider the application of storage batteries to their own plants, and thus the accumulator has assumed great importance at the present time, especially as power and light stations are so far developed that further increase in generating capacity means large additional expenditure, and in a great many cases the rebuilding of the entire plant.

Realizing, therefore, that storage batteries are eminently practical as auxiliaries, and that their utility and value are acknowledged throughout Europe, it is not surprising that engineers and managers in this country are inquiring about them with the end in view of securing the full measure of their advantages and benefits. In England and on the Continent, storage batteries have been used in central stations for more than five years, and the success of their application has brought about a great change of feeling regarding them; and the respect with which they are now regarded is an ample indication of the value they have been to managers in the operation of their stations.

It is an acknowledged fact that the great variations and fluctuations of the load on power circuits, especially those power circuits supplying trolley lines, are among the greatest difficulties which engineers have to contend against, and any appliances which will aid them to arrive at a satisfactory running of their station is looked upon with favor by them. It is only in the ranks of those short-sighted engineers, where ignorance and prejudice are the rule rather than the exception, that there are found

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men who will refuse to consider the storage battery as an auxiliary.

In this paper the term "variation" is used to designate the change of current induced by the adding of lights onto a lighting station, or the cars or motors onto a power station. The term "fluctuation" is used to indicate those rapid and necessary changes of current taking place on the outside line, due to stopping or starting of cars or throwing on or off of stationary motors. Although they may be thus differentiated, they bear a certain relation to each other, and in applying a storage battery a study of the conditions will quickly indicate the type of battery which will be more favorable in each case. By the "type" of battery is meant the slow discharge battery for a long period of service, or the rapid discharge battery for a few hours, or even less time of discharge.

In the lighting station, if we bear in mind the usual form of curve, it will be remembered that the instantaneous changes of current are minute and almost imperceptible, compared with the steady increase or diminution of the total current of the station. Comparing the lighting curve with the usual form of power station curve, it will be noticed that the instantaneous changes of current are enormous compared with that in the lighting station curve. There is a similarity in the two curves in the fact that at certain hours of the day more cars are operated than at other hours, thus producing a general rise in the level of the power curve, corresponding to the throwing on of a number of lights in the lighting curve.

It is not the purpose of this paper to discuss the characteristics of the two curves, but to consider in a general way the application of storage batteries to the wiping out of the fluctuations and variations as they come upon the dynamos and engines. The introduction of a storage battery into a central station, acts in a certain sense as a buffer between the external load and the dynamos, taking the shock of the variations without throwing the same on the engines. In this regard they have the effect of reducing the average percentage variation in load on the dynamo, from a large amount to a very small one, making the operation of the machines more efficient. In fact, a storage battery acts as a regulator in this instance, maintaining as it does a constant voltage at the switchboard. This introduces the question of the efficiency of engines with varying loads; and, leaving out of account the reports by engine builders, who are naturally interested parties, it is a fact that not many extended and careful investigations of efficiency under varying loads have been carried out. Prof. W. C. Unwin, of the Central Institution, at South Kensington, has shown, however, that a decrease of mechanical efficiency has a serious effect on the economy of working with a variable load, and with a load varying from 100 per cent. to 25 per cent., the efficiency decreases from 85 per cent. to 40 per cent.

As applied to power stations, and especially where water power

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is used, storage batteries are almost indispensable. The writer knows of several plants where the successful maintenance of a constant voltage on the machines is dependent upon the fact that an attendant sits by the governors of the wheels, and regulates them by hand, as the inertia of the water, even when the best water-wheel governor that has ever been produced is employed, is too great to allow the turbines to pick up or throw off the load with anything like the quickness with which it is thrown on or off by the outside circuit. The stations in mind are not small stations, as might be supposed at first thought, but are stations where several thousand horse power and over, are generated at certain hours of the day; and it is surprising that engineers of intelligence, who are usually quick to perceive the advantages of new applications, are still allowing their prejudices to prevent them from investigating the merits and value of accumulators as regulating governors in their stations.

In the application of storage batteries to the power station of a trolley system, it is not unusual to find the variation in load as much as 50 per cent. below the average horse power, and even as great as 200 per cent. above the mean load. These enormous fluctuations take place in the course of a few minutes, and are an expense to the railroad companies in at least three ways. In the first instance, they require the use of a dynamo capacity very much in excess of that required where the station is operated at a constant load. In the second instance, these fluctuations reduce the life of the machinery of the station, producing a very large depreciation account. In the third instance, the efficiency of the generating plant is very much reduced, as pointed out in a previous paragraph. It has been figured out in a number of instances that could the steam be utilized in a proper manner in the engines driving the dynamos, that at least 40 per cent. more work could be obtained from it.

When considering the application of storage batteries to illuminating plants, it is found that their value is equally as great as in the case of power stations, as the charging of the battery can be done while the plant is operating at light loads, thus making use of the power of their machines to great advantage. At the period of heavy load, the battery is able to take care of the peak of the load, and also to operate the lights during that period of the 24 hours when few lights are being supplied from the station.

The value of an accumulator plant attached to an illuminating station has been thoroughly demonstrated by the New York Edison Illuminating Company, and the Edison Illuminating Company of Boston, and recently in the plant of the Lawrence Gas Company, Lawrence, Mass. In the latter case the battery is used in connection with their Edison three-wire system, and is used in the regular way of carrying the peak of the load during the busy hours of lighting. The Lawrence Gas Company, after

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operating this plant for a short period, have recently doubled their storage battery, as they have found it so convenient and useful that they believe their system would be much benefited by an increase.

The storage battery can also be used as a valuable adjunct to both power and lighting stations at points in their systems where it is difficult to maintain the voltage at periods of heavy load. In these cases the feeders are usually not sufficient to carry the whole current direct from the station. But during the periods of small load the feeders can be utilized up to their maximum allowable drop in potential, to charge battery sub-stations placed at these weak points. When the load at such points becomes greater than the capacity of the feeder, the battery comes into play, and carries the load in connection with the station supply at that point, thus maintaining the voltage and doing satisfactory and valuable service. There must be hundreds of street railroads in this country that have just such weak points, and it will only be in accordance with the established progressive character of American street railway and lighting engineers, to investigate the value to them of a storage battery, as soon as it has been brought thoroughly to their notice. This cannot but result in a widely extended use of the storage batteries for this purpose; and the expectations of those interested in storage batteries would not be exceeded if half the street railroads and direct current lighting plants in this country and Canada should adopt within the next few years storage batteries either at their central stations or at sub-stations, the more especially as they can now obtain storage batteries which are thoroughly reliable, and which can be installed under a guarantee.

The extent to which storage batteries have been used in England and on the Continent is very great; and it will surprise many engineers in this country to know that there are more than 20 lighting stations and several thousand isolated plants in Great Britain alone, using storage batteries. Further than this, there are in Germany 5,000 isolated plants and 15 railway power plants using storage batteries. In fact, 80 per cent. of all the central stations in Germany and Austria are equipped with storage batteries. In addition to the above, there are many stations in France, Italy, Holland, Belgium, Sweden, Norway, Denmark and Spain, and two or three in Switzerland.

A survey of the progress which storage batteries have made in European countries, indicates no very great change in the principles of construction, but the results seem to be rather due to a thorough analysis and appreciation of the requirements of each case. This has resulted in a proper use of batteries and a correct recognition of the limitations of their usefulness. This fact alone has contributed largely to their successful application. The great difficulty in this country has been that engineers have not recognized a proper limit to the usefulness of a battery, but have, in

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many cases, far exceeded their specified limitations, and in this way have injured the batteries and cast discredit on them. It would be just as reasonable to overwork an engine until injured or worn out, and then declare that all engines were useless and expensive mechanical contrivances.

One point which has contributed largely towards the success of storage batteries in Europe, is the fact that engineers have endeavored to obtain long life and high efficiency even at the expense of increased first cost, and instead of attempting to obtain a large output per pound of element, they have limited themselves to a reasonable number of ampere-hours per pound. The result of this has been that the batteries in use in Europe have shown great endurance and solidity. The experience, however, which has been obtained with many American batteries has not been so promising as on the Continent, owing to the lack of proper appreciation of them. It would be greatly to the advantage of American engineers if they would follow the lines laid down by their European confreres; and if, instead of waiting for some marvelous development in the manufacture of storage batteries, they should make use of the existing high class and efficient batteries which are now offered to the public, and by using them in a reasonable manner they would obtain valuable and even remarkable results.

Great progress has recently been made in manufacturing large batteries which have a capacity large enough to take care of the needs of central lighting and power stations, and engineers need no longer complain that they are unable to get the large cells which they require. In fact, manufacturers can produce cells having almost any given capacity.

Considering the efficiency of a storage battery, the factors which tend to reduce it are due to a loss in voltage, and in the quantity of current. These losses, however, are not so serious as they have been in the past, and manufacturers are at present able to guarantee a very high efficiency. In cells which were submitted to Prof. H. L. Callender, an ampere efficiency of 96.1 per cent was recorded, the watt efficiency being 84 per cent. In certain instances, however, known to the writer, these efficiencies have been slightly exceeded, and complaints from central station managers that they cannot obtain efficient cells are now groundless, as with the efficiencies named, an eminently satisfactory service can be obtained. It must be borne in mind that a loss of 16 per cent., or even 20 per cent., in the efficiency of the battery does not mean the loss of the same percentage in the output of the station, as the battery usually supplies, approximately, or even less, of the whole output in watt-hours, and it is, therefore, from that fraction of the whole output that the loss in the battery must be deducted.

In the matter of cost of maintenance of a storage battery outfit, it is now usual for the manufacturer to guarantee a fixed

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annual percentage. This percentage varies from ten per cent. in small plants to a smaller percentage in large plants, depending, of course, on the conditions of operation and the use to be made of the battery, a study of which will soon determine what percentage can be guaranteed. In first-class plants well installed and operated by careful engineers, the cost of maintenance can be reduced to the vicinity of 3.5 or 4 per cent. It is customary for the manufacturers to enter into a contract, in the case of large plants, guaranteeing that the cost of maintenance shall not exceed a certain percentage per annum for the period of contract. This can be carried out in two ways. Either the lighting or railroad company can pay the manufacturer the percentage specified, every year, and the manufacturer will inspect and keep the battery in first-class condition; or the company employing the batteries can inspect and order renewals themselves, in which case should the cost of maintenance exceed the percentage guaranteed, the manufacturer will not charge more than the specified amount. This is an exception rather than the rule, however, as the cost of maintenance is usually somewhat lower than that specified by the manufacturers, so that the company owning the battery is the gainer by the difference in percentage. By a thorough attention to details, both large and small, the percentage can be kept down to a very low figure; and it is to be regretted that the practice of engineers which prevails in Europe, of treating the battery with care and consideration, does not seem to exist among the engineers of this country, to the detriment of their own lighting or railroad plants, which would otherwise be able to utilize batteries in an efficient manner.

It must not be assumed from the above that storage batteries require an inordinate amount of care and trouble. On the contrary, they do not require either expense or great care. All that is demanded is regular and systematic attention on the part of those having them in charge. When such care is exercised, it is found that batteries perform a very valuable service, and largely reduce the operating expenses of the station—in many cases as much as 30 to 35 per cent. This reduction in operating expenses is, of course, due to the saving in cost of coal consumed, a saving which could not otherwise be obtained. Where water power is employed, a storage battery enables the water-wheels to be operated for 24 hours, storing current while the station output is reduced to a minimum, and aiding the station during the busy hours of the day. In many cases this practically doubles the output of the station without increasing the cost of installation to a corresponding amount. In fact, in many cases where water power is used, it would be impossible to double the power of a station, as there would not be enough water at hand to give double the power. This is especially true in those sections of the country where the power of small streams has been utilized and where the flow of water is continuous but not very great. In

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addition to a storage battery acting as a receiver for storing the current while the station is not giving a large output, it also maintains, during the operation of the station, a perfectly uniform voltage, which would not be obtained with the varying load direct upon the water-wheels, on account of the difficulty in governing previously mentioned.

When an entirely new power plant is to be built, there is no doubt that by adopting the storage battery in the first instance, the initial cost of installation will be less than for the plant not using storage batteries, and the cost of operation of the station will certainly be very much reduced, when the station uses storage batteries. In the case of existing plants which have to be extended, it has been proved that a kilowatt-hour capacity can be added more cheaply to the station by the addition of storage batteries, than by the addition of generating machinery; while, of course, the cost of operation is much reduced.

Referring to the primary cost of storage batteries, the cost per kilowatt-hour output is relatively greater for small cells than for large ones, since the cost of manufacture is reduced per kilowatt-hour in the larger sizes, whereas the jars and tanks which are used to hold elements do not decrease very much with the decrease in size of the elements. The cost of shipment and erection are, of course, slightly less per kilowatt-hour with the larger sizes than with the smaller ones, and on the whole the cost per kilowatt-hour with the larger cells is less than with the smaller sizes. It is stated by the Electric Storage Battery Company that they are now installing large plants of the Tudor type at a cost per kilowatt-hour of about $37 to $40, which cost, it is understood, can be reduced in the larger stations. The question of cost, however, is one which must be studied out in each case where it is proposed to install storage batteries, and a consideration of the cost of installation of storage batteries with their attendant reduction in operating expenses, will very soon bring to the mind of purchasers that it is cheaper to invest in accumulators than to invest in additional boilers, engines and dynamos.

As previously stated, it has been the object of this communication to bring before the INSTITUTE the general facts and considerations relating to the installation of storage batteries as auxiliaries to power and lighting plants. Lengthy descriptions of plants already installed have been avoided, and those interested are referred to the published descriptions which are constantly appearing in the technical journals.

THE PRESIDENT:—Gentlemen, there is probably no one who has had more experience in storage battery work than Mr. Edgar, and I would like to call on him for the next contribution to this discussion.

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Communication by C. L. Edgar on "Practical Experience with Storage Batteries in Central Stations."

To those interested in selling electricity, it is a source of great satisfaction that the storage battery discussion has, within the past few months, especially in America, taken on an entirely new phase. It has become a question of use, and not of manufacture.

For years we have all watched with great interest the various types of batteries put upon the market. We have discussed their value, at first deciding for ourselves whether they would work at all, and in later years broadening out the discussion as to how well they would work. We have watched the various companies interested in the manufacture of storage batteries fight one another in the courts, and we have wondered if it were ever to be possible to obtain a battery which did not infringe some one else's patent.

Until very recently it has not been possible to discuss from the standpoint of experience the economic merits of storage batteries, and it is particularly satisfactory to us to note that the discussion seems to have drifted away from the manufacturer to the user. To-night I am going to assume, at least for the purpose of this communication, that these perplexing questions have all been answered, and that we are finally on a par with our neighbors across the water, prepared to discuss the advantages of a commercial storage battery found ready to our hand.

Whatever may be the facts as to the existence of a commercial battery, some of us have purchased and are operating batteries which we consider satisfactory, and I will leave that part of the discussion to others, confining myself exclusively to their uses in an Edison system of circulation and distribution for lighting and power purposes, in thickly settled communities. As it appears to me, their uses can be classed under four great heads, as follows:

1st. To carry the peak of the load at maximum hours.

2nd. To carry the entire load at minimum hours.

3rd. To act as an equalizer or reservoir.

4th. For the equipment of annex stations.

There are many other special uses for batteries which can be naturally classed under one of these heads.

First, to carry the peak of the load.—In all systems of lighting, whether by gas or by electricity, there is a considerable portion of the connected load which is used only for two hours per day during the three or four months in winter. We have all of us, at various times, very earnestly discussed the probability of being able to widen out this peak as it is commonly known, and numerous schemes have been devised by which it has been made more or less of a hardship for customers to use their light at this time, special concessions being made at all other hours of the day or

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night. It does not seem to me that any of these will avail. We cannot get around the fact that there are. in every large city, hundreds of stores which close up at six o'clock at night. The only need which they have for light is after it becomes dark. In this section of the country, darkness comes on about 4.30 in midwinter, and these stores are bound to use their light from 4.30 to six o'clock, and have no need of it at any other time. These are facts which are entirely outside of the question of electric lighting, and nothing which we can do will change them.

It matters not whether the company has a large motor load in the daytime, or a large city contract at night. These are simply going to change the height of the curve at those hours. They are not going to alter the special shape of the curve due to the hour and-a-half of darkness during the business day.

This particular peak will be in some cases a much larger percentage of the total maximum output of the station than in others, but I think it is safe to assume that it is likely to vary only between one-third and one-half of the total. In the case of the company with which I am connected, we have found that if we divide our maximum load of the year into two parts. the upper half exists only for about two hours under ordinary circumstances, and four hours under exceptional circumstances for the five winter months.

Computing the kilowatts in these two halves, we find that the lower half contains 90 per cent. of the K. W. hours manufactured, whereas the upper half contains only about 10 per cent. This would prove the position taken by some engineers that if an extremely large station was to be constructed, it would probably pay to equip it with two types of apparatus—50 per cent. to be of the best economy and most expensive class known to the art. This to do the 90 per cent. of the work. The other 50 per cent. to consist of crude, cheap, uneconomic but reliable apparatus, to do the 10 per cent. of the work. The saving in interest on the lesser investment in the second class would be much greater than the extra cost of running this half, due to its poor economy.

In our particular case we find ourselves in precisely this position. Our company installed in years past about 4,000 H. P. of high speed, belted, bipolar apparatus, reliable but of poor economy. Some three years ago it changed to the other extreme and commenced to equip with the highest priced and most economical apparatus to be found in the market, and to-day there is about 4,000 H. P. of this apparatus in use.

The data which we have for 1894 and 1895 proves the statement which I have just made. Ninety per cent. of our kilowatts have been manufactured by the vertical, triple expansion, multipolar units, and yet the total capacity of this apparatus is not over 50 per cent. of our maximum output for the winter.

The application of the storage battery to these conditions is obvious. What we need and what all companies under generally

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like circumstances need, is a piece of apparatus capable of doing two hours' work per day which is cheap, and which has fair economy. If storage batteries could be used under no other circumstances than these, it is, perhaps, somewhat doubtful whether it would pay to install them, but yet I am inclined to think that considering their first cost and the efficiency which we can obtain from them, it could be fairly proved that it would pay to use them rather than what I have designated as the cheap type of apparatus.

At the time our first battery was purchased, our standard unit was 650 H. P. We therefore called for a battery of 650 H. P. capacity for two hours. We eventually, under stress of circumstances, reduced this to one and a half hours and found that it cost considerably less than a first-class steam plant.

As all apparatus has to be installed for the express purpose of taking care of the maximum load, it seemed to us very clear that if we could save in our first investment by installing storage batteries which cost less than a steam plant, we were going to be able to do a given amount of work with a less amount of capital by this means than by any other. We thus decided to install a battery to take care of the peak, even if we obtained no other advantage from it.

Second, to carry the entire load at minimum hours—I think that the nature of the load curve in America is against the use of batteries for this purpose to anything like the same extent as abroad. With us there is only about six hours of minimum load, whereas, owing to the lack of motor business in Europe, the minimum there extends some days from midnight until three o'clock in the afternoon. Our minimum is so short that we are not able to save one shift of men nor are we able to save much in the fixed boiler room expenses from drawing the fires, banking the boilers, or any of the various other expedients used when the plant is not in operation.

Our generating department has gone through some exhaustive experiments, running first the engines for 24 hours a day, charging the battery at minimum load, and then turning around the next week and shutting down the steam plant for the six hours from midnight until six o'clock in the morning, and depending entirely upon the battery. The general conclusion seems to have been arrived at that the former is the cheaper method. Admitting this, the indirect advantages of the former, by which the battery is charged during the night, and can be used during the following day, are very much greater than if the battery were discharged during the night, as it could not be completely charged again until the middle of the afternoon of the following day.

I do not consider our conclusions final, as the local conditions might materially change the result. In our case it happens that the output at night plus the charging current of the battery, is

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just equivalent to one of our standard units. If it were necessary to run two units to do this work, our conclusions might have been different, so that I think this is a case which has to be decided in each place on its own merits.

Third, to act as an equalizer or a reservoir.—It is this use of the battery with which we have been particularly pleased, and in order to understand, it is perhaps desirable to explain the needs which a modern station has for apparatus of this kind. Years ago a distribution company was equipped with one station, furnishing electricity through a system of feeders, supplied from one 'bus bar. All this is changed. To-day the modern station manufactures electricity in various places, transfers it from one station to the other at will, sends it out through a system of distribution at three or four pressures supplied from 'bus bars of varying potential. At the minimum hours of the day the electricity is manufactured by one set of dynamos, part of it being delivered to the 'bus bar in the station in which the dynamos are located, the remainder being sent out over tie lines to various annex stations and delivered there to the local 'bus bar. The amount of current is so small compared with the capacity of the various circuits that, practically the pressure delivered at the lamps is constant, notwithstanding the various roundabout ways in which it reaches them.

As the load begins to increase, the drop over the tie lines becomes noticeable, and it is necessary, by means of auxiliary dynamos known as boosters, to raise the potential of that part of the output which is delivered to the tie lines.

The load still increasing, it is necessary to start additional dynamos. These may be thrown in multiple directly with the original pair, and deliver the same potential as the others, or, if the condition of the load warrants it, they may be thrown in multiple with the original dynamos and the booster in series, and deliver the potential needed by the tie line. In this case the booster might be taken out of circuit.

The load on the tie line again increasing, the booster would be again put in use, and we would thus have the condition of a tie line supplied partly by a dynamo of the proper potential, and partly by additional current furnished by a booster, raising the potential from another 'bus bar supplying current locally.

This goes on until nearly the maximum load is reached. It then may be found, as it is sometimes in our case, that the original or main station is not equipped with sufficient dynamos to supply the local distribution. In this case the current over the tie line is reversed, and the annex station sends current to the original station, which arrives there at somewhat lower potential than is needed, and is there raised by means of a booster to the 'bus bar of that station. It is necessary to understand that these are every day occurrences, and if we were not equipped with a battery, it would be almost an hourly question as to what it was

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necessary to do next, whether to start dynamos, stop them, change boosters or any other of the innumerable combinations which might be made. This trouble is intensified by the uncertainty as to what changes are going to take place in the output, and what the load is going to be at any given time. In a very large degree the battery answers all these questions or at least makes them unimportant. It makes it possible to determine beforehand what the regular day's work of the steam plant is to be, to decide how many and at what time boilers are to be put in service, when engines are to be started or stopped, and in general to operate the plant to its best economy, knowing that daily or hourly inequalities in the load, or uncertainties caused by the weather will be taken care of by the battery.

It is kept in multiple with one or the other or all 'buses at all times. It is supposed, for many hours of the day, to be standing idle with the ampere-meter at zero, but it may, without a moment's warning, be called upon to either give or take anywhere from one to 3,000 amperes on a side. It is possible in this way theoretically to keep every engine which is running, loaded up to its maximum economy at all times. Practically we have found it possible to never operate an engine with less than three-quarters load. The economy of the steam plant then more nearly approximates what is known as mill practice, which is the goal toward which we are all striving.

Having satisfied ourselves in the beginning that with a given amount of capital we could do more work with the battery than without it, we by actual practice came to the conclusion that we could by the same means do this same amount of work more cheaply. When we remember that we installed the battery for the express purpose of taking care of the maximum load, we are, of course, particularly pleased at the very great use we can make of it for this purpose of equalization, and yet, in addition to this, we have made enough tests to prove to our own satisfaction that we do not lose anything in fuel economy by this particular use of the battery. The watts lost by the inefficiency of the battery are made up more than fourfold by the better economy of the steam plant. We have taken typical winter days and figured out exactly the cost of running our system with the battery and without, and have proved that the actual coal consumed with the battery is a material amount less than without it. If, in addition to the fuel, we take into account the very great saving in the labor, the added reliability and the better service given, we will see that these uses of the battery are even greater than those for which it was originally installed.

I do not think it is possible to overestimate the advantages of storage batteries for the purpose of giving regularity and reliability to a system of distribution. With very sudden fluctuations in the load which are continually taking place, it is almost impossible with dynamos alone to regulate the 'bus pressure so

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quickly that the pressure throughout the system remains constant. Of course, we have done this for years to the best of our ability, but it has necessitated keeping everything in first-class shape and having the employees of the company on the alert at all times to take care of this question. The uses of the battery very much simplify this problem. Very many times where in the past it was necessary to change the magnetism of the fields of dynamos, it is now necessary to do absolutely nothing, the battery acting as a reservoir, giving out quantities of current without any apparent change in pressure for the time being.

This question of regularity is very closely connected with the one of reliability. To those of us who are identified with central station work, there is a great sense of security when we realize that whatever may happen to the steam plant, we have sufficient battery to carry us over a few minutes of disorder. In our particular case, we have at the present time sufficient battery to run 60,000 lamps for five, ten or fifteen minutes, depending upon how great the emergency is. This advantage of the battery may not appeal to an outsider. I do not think they can realize the intense nervous strain to which all connected with the successful detail operation of the station are subjected. If a battery and a steam plant were on a par in all other respects than this, I should personally feel very much inclined to install it for this reason alone.

4. *For the equipment of annex stations.* This is a use to which we have looked forward with great interest, but up to the present time have had no occasion to make the use. There are in every city certain sections, located so far from the centers of distribution that it becomes a very serious and expensive matter to reach them with the regular three-wire system.

When we realize that it makes very little difference to which end of a tie line a storage battery is connected, we can see at once the special advantage which this type of apparatus gives us. If of such value that it will pay to install them, it is a matter more or less immaterial whether they are installed at the main station, or at an annex station connected to the main station by tie lines.

The fixed charges of running a battery room are very small as compared with those of a steam station, and there would not be any very material increase of fixed expense between one large battery located in a central point and half-a-dozen small ones distributed throughout the city.

Storage batteries, therefore, lend themselves particularly to the location of a "central" station at some convenient point upon the water front, and the building up of small centers of distribution scattered throughout the city, consisting of storage batteries with or without a steam adjunct, and connected together possibly, but certainly each one connected to the central station.

This communication may be considered to have been written upon very narrow lines and I may say that this was intentional.

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So much has been written during the past few months upon generalities and upon possible cases which may or may not exist, that it is sometimes valuable to brush these all one side and to confine oneself to some specific cases. This I have tried to do.

Our company has used the first battery 20 months, and one of double its capacity for six months, entirely too short a time to come to any conclusions about the depreciation, but it has given us ample time to satisfy ourselves as to the economic value. It is sufficient for me to say that if a need should arise to-morrow for additional capacity, either at our main station, at either of the annexes or in any new part of the city, within reasonable distance of our center of distribution, we should consider the question along the lines which I have just indicated. We should eliminate entirely from the discussion, the question which has distracted the public mind for so many years and decide it entirely upon its merits, placing the battery side by side, and on an equality with other modern and improved apparatus.

THE PRESIDENT:—You have heard the exceedingly interesting and important contribution of Mr. Edgar. The next communication is from Mr. Nelson W. Perry.

COMMUNICATION BY NELSON W. PERRY, E.M., ON "THE STORAGE BATTERY OR THE GAS ENGINE AS AN AUXILIARY."

Whether it is economical or not to equip a central station with an auxiliary storage battery plant, is a question which must be decided separately for each particular installation. Generally speaking, the question will be decided by the character of the load line—a broad topped curve being the most unfavorable, and a sharp peak the most favorable to storage battery economy. Again, a station having a very light day load may use the battery to good advantage even though its night load may present a broad-topped aspect.

Aside from purely economic reasons, convenience may be controlling, so that it is impossible to state unless all the conditions are known, whether the storage battery is advisable or not.

The price of the battery is an important element of course, but less so than popularly supposed, for the space which it occupies and the cost of maintenance may largely overbalance any gain in first cost over the cost of the extra boiler, engine and dynamo.

In regard to the cost of maintenance, manufacturers are willing to guarantee that it will not exceed 10 per cent. per annum, but it is well to understand just what this 10 per cent. means. It means, in the first place, that if you put in all the battery power that the manufacturer recommends, and take care of the battery exactly as he says, then the guarantee holds good. Under such

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conditions the manufacturer is undoubtedly safe, but if we install a plant under these conditions we are pretty sure to find that the economy in first cost of the battery over engine and dynamo has entirely disappeared.

Then it is well to understand beforehand what the 10 per cent. means—10 per cent. of what?

Some time ago I had occasion to inform myself accurately on this subject and to this end entered into quite a correspondence with the president of the leading storage battery company of this country. As regards the guarantee, he wrote me under date of June 18, 1894, as follows:

"We send you by to-day's mail our illustrated catalogue and "would especially call your attention to the question of main-"tenance as contained on page 11. We undertake, in these cases, "to provide renewals when renewals are required, at a specific "price with a guarantee that this will not be required sufficiently "frequent (*sic*) to exceed an average of 10 per cent. per annum. "We have every reason to believe from our experience so far, "that the actual cost of maintenance when the batteries are used "at normal rates will not exceed five per cent."

Turning to page 11 to see what this meant, I found the following:

"This company is prepared to undertake maintenance con-"tracts according to a scheduled rate of charges, for periods up to "ten years or longer, under which they will guarantee that the "total amount paid for renewals during the term of the contract, "shall not exceed ten per cent. per annum on the *catalogue* price "of the cells specified in the contract. . . . . *In all cases of re-"newal by* contract the old material becomes the property of "the company, *and must be returned to their works free of "charge for carriage or packing.*"

[The italics are mine.]

Since the regular trade discount at that time was 20 per cent. of the catalogue price, and a further discount was offered which made the cost of the batteries comparable with that of an engine and dynamo, the guarantee assumed a very different aspect from that which it bore on its surface. When to this was added the cost of packing and carriage back to the factory, it ceased to be an attractive guarantee, and my calculations showed that in many cases where the storage battery might be recommended, if the guarantee was what it appeared to be, it would not be economical under the guarantee as it actually was.

As before indicated, there are some situations in which either convenience or extreme steadiness of current may be controlling in deciding the question of the use or not of storage batteries. But where the question is one purely of economy, I would not myself recommend their use under any circumstances, simply because there is a still more economical method at hand. I refer to the gas engine. Even if it were necessary to use illuminating

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gas from the street mains it would be more economical (considering space and other factors), to take the peak of the load with a gas engine than to install a battery for this purpose. In this case there would be no standby losses and the engine would be ready at a moment's notice to be thrown into service.

It is a fact that has been amply demonstrated by others as well as myself, that a given number of lights can be produced with half the gas burned in a gas engine that is required to produce them in ordinary burners. The mechanical efficiency of the gas engine is not quite so high as that of large compound condensing steam engines, rarely ever exceeding 83 to 85 per cent., while the latter may go to 90 per cent., but the total efficiency from fuel to the pulley of the gas engine is about double that of the steam engine—reaching 25 per cent. under favorable conditions, whereas, with the steam engine it rarely equals 12 per cent. So that with the gas engine operating at anywhere near its full load, there would be a gain in efficiency, instead of a loss of say 20 per cent. where the battery was used.

As indicating the performance of a gas engine using illuminating gas at various loads, I quote the following figures obtained from a test of a 12 H. P. (actual) gas engine.

Actual H. P. developed.	Gas consumption (cu. ft.) each actual H. P.
12	15
11	15.3
10	15.5
9	16.
8	16.5
7	17.
6	18.
5	19.
4	21.
3	26.
2	30.
1	48.

These figures are somewhat better than would be obtained in practice, but go to show that the gas engine compares favorably at light loads with the steam engine under similar conditions.

Thus far I have spoken only of illuminating gas, but the power may be much more cheaply generated by using a fuel gas.

The cost of producers or generators comes to about $11 00 per H. P. capacity—considerably less than the cheapest boiler, and an idea of the space required may be gained from a statement of Mr. J. Emerson Dawson who in estimating for a plant of 400 K. W. capacity says that if the gas plant is all on one level it would occupy a ground space of 27 feet by 54 feet, but if necessary, all except the gas holder can be placed under or over the engine room. His estimate for such a plant is, including erection, foundations and ash pit for generators $5500 or $10.38 per H. P.

These fuel gas generators can utilize advantageously the poorest grades of fuel, and produce from the better grades of anthracite about 160,000 cubic feet of gas of a calorific value equal to one quarter that of 16 C. P. illuminating gas, per ton of coal.

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As to the standby losses of the gas producers, this has been very carefully determined in a number of cases. As an illustration I will cite a single case—by no means the best on record.

At Openshaw a generator which supplied gas for from 250 to 300 I. H. P. was shut down for 41 hours, and the fuel consumption during this time was but 3.9 pounds per hour or about one per cent. When we compare this with the stand-by losses of the steam boiler which is estimated by Prof. Kennedy at ten per cent. of the total consumption in all the boilers, we see how insignificent it is.

A situation usually considered peculiarly adapted to the storage battery is in subordinate or outlying stations where they are charged during the day time from the central station, and act as centers of supply during the night time.

But gas can much more economically be distributed to these stations than can the electric current, for Mr Denny Lane[1] has shown that with ordinary 16 C. P. gas, 3000 H. P. can be sent a mile for an expenditure of one H. P., or one-thirtieth of one per cent. of the power conveyed.

My own calculations show that a six-inch pipe will deliver 6,000 cubic feet of gas per hour at a distance of 10,500 feet under four inches of water pressure. If this be 16 C. P. gas, allowing 25 cubic feet per H. P. hour, this quantity represents 240 H. P.

Cast-iron pipe, six inches in diameter, having a thickness of $\frac{1}{2}$ inch, weighs 31.9 lbs. per foot. The total weight of this two miles (nearly) of pipe will therefore be 334,950 lbs. This would be equivalent in conductivity to about 41,869 lbs. of copper. But four miles of copper weighing 41,869 lbs. would be equivalent to about four No. 000 B. & S. wires, which would have a resistance for the four miles of 0.325 ohms. If the charging current were transmitted at 220 volts, there would be required a current of 848 amperes; but a wire having a resistance of .325 ohms will only deliver under a pressure of 220 volts 220 ÷ .325 = 677 amperes, there would, therefore, be required five No. 000 B. & S. wires to deliver this energy, and the weight of this would be 53,540 lbs.

If the distribution took place at 1,000 volts, the amperes required would be approximately 180. To deliver this at the same distance with a loss of 10 per cent. would require 6,264 lbs. copper, and to deliver it at one per cent. loss would require 62,642 lbs. which would cost far more than the pipe, and still give less efficient transmission.

I think it would be very easy to prove that the gas engine with fuel gas, would prove a much more economical auxiliary to the central station for taking the peak of the load, and the loads amounting to fractions of a unit, than the storage battery, and

1. *Electrician*, Oct. 9, 1891.

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when we consider the efficiency of transmission of energy in the form of gas, which will permit of the location of the gas generators where land is cheap and fuel easily procured, it seems to me that the plan must commend itself to electrical engineers.

Unfortunately the gas engine business in this country seems to be in the hands of parties totally incompetent to handle it properly, as every one knows who has ever had occasion to seek information from them.

It is probably not too much to say that every attempt thus far made in this country to adapt the gas engine to electric lighting has proved a failure. Our own manufacturers either do not know what their engines are capable of doing, or else they are afraid to make public what they will do. I believe there is not a single manufacturer who has a printed price list, and my own experience and that of others whom I know, has been that it is impossible to get prices quoted, until the manufacturer or his agent has been thoroughly satisfied of the exact purpose for which the quotations are desired. Information of any kind is almost impossible to get; and guarantees of performance, when given, are worthless. To such an extent is this true, that nearly all, if not all the recent large orders for gas engines have gone abroad where the business is conducted on business principles.

In England, Germany and France the gas engine has come into extensive use in isolated lighting, and already has been adopted with satisfactory results in several central stations of considerable size

When the business is properly handled in this country, we may expect to see the gas engine make its way rapidly in the lighting industry here also, for it has merits which need only be known to be appreciated.

THE PRESIDENT:—The next communication is from Dr. Crocker. on the "Use of Storage Batteries in Electric Lighting."

DR. FRANCIS B. CROCKER:—In spite of the fact that my communication was printed in advance of Mr. Edgar's, I think that he has really anticipated me in the subject matter, and has gone much further than I even attempted to go. He has already given you the uses to which storage batteries may be put in central stations. I have considered the matter rather more generally, that is to say, I have attempted to give the various possible applications in electric lighting, but I did not try to cover any of them very completely.

COMMUNICATION BY DR. FRANCIS B. CROCKER ON THE "USE OF STORAGE BATTERIES IN ELECTRIC LIGHTING."

The function of accumulators is to receive electrical energy at one time or place, and to give it out at some other time or place.

The principal uses to which they may be put in electric lighting are the following:

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1. To supply portable electric lamps.

2. To take up fluctuations and thus steady the voltage or current.

3. To furnish energy during certain hours of the day or night and enable the machinery to be stopped.

4. To aid the generating plant in carrying the heavier load which usually exists for only an hour or two.

5. To make the load on the engines more uniform by charging the battery when the load is light

6. To transform from a higher to a lower potential by charging the cells in series and discharging it in parallel, or *vice versa.*

7. To subdivide the voltage and enable a three or a five-wire system to be operated with a single dynamo.

8. To supply current from local centers or sub-stations.

Each of these applications will be considered separately in the above order.

1. *Portable accumulators.*—The accumulator is practically the only means of supplying portable electric lamps or those which are not connected to a dynamo even if they are stationary.

The primary battery is expensive and troublesome to operate, and it has never been commercially successful for electric lighting, except where only a few small lamps are required. Nor is there any other satisfactory primary source of electrical energy except the dynamo driven by mechanical power. It is therefore practically essential to adopt accumulators wherever portable electric lamps are used.

The serious drawback with portable accumulators is their great weight. For example, a standard size which weighs 100 pounds, yields ten volts and five amperes, or 50 watts for ten hours, which is just sufficient to feed one ordinary incandescent lamp of 16 candle power. This weight would be prohibitive in most cases in which the only way to carry the battery was by hand, but it might be allowable for lighting railroad trains, where the weight would not be so objectionable.

Their great weight would also discourage in most instances the use of accumulators for supplying lamps in places which are not connected to a generating plant, the batteries being carried back and forth from a charging station. This method might be resorted to on special occasions, such as a fete, to which ordinary commercial limitations do not apply, but for regular lighting it would be troublesome and expensive.

Small accumulators are used to feed miniature lamps for medical or dental purposes, in which case their weight is not a serious difficulty in view of the importance of the work and the small amount of energy required. Small batteries are also employed for theatrical lighting effects in which the lamps and batteries are carried by the performers when it it is not convenient to supply lamps by a wire connection.

2. *Accumulators for preventing fluctuations*, due to unsteadi-

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ness in the driving power, are often applied successfully. A dynamo driven by a gas engine, for example, may vary periodically in speed because of the explosive action of the gas in the cylinder, and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. But improvements in design and construction tend to reduce unsteadiness of speed, and by the use of a heavy fly-wheel, and an elastic connection between the engine and dynamo, the result is sufficiently satisfactory in most cases to make a battery unnecessary. An accumulator is generally installed in connection with a small gas engine lighting plant, to enable the engine to be stopped for a considerable portion of the time and thus save labor and attention, in which case the battery may also act to prevent fluctuations, but its principal function is the former one which will be considered next.

A windmill electric lighting plant absolutely requires an accumulator or some other means of storing energy not only to eliminate fluctuations in speed which are constantly occurring, but also to bridge over the considerable periods of calm weather.

3. *Accumulators to enable machinery to be stopped* during certain portions of the day or night. The advantage of this application depends upon the fact that in almost every electric lighting plant there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

This plan also allows the machines to rest and cool down which greatly facilitates cleaning and repair. In a hotel, residence, or on board of a yacht it may also be very desirable to stop the machinery and avoid the vibration and noise during the night. On the other hand, the addition of an accumulator to an electrical plant renders the latter heterogeneous, since the battery and its management differ so radically from the machinery and the handling of the same. It must also be remembered that the total investment is increased by the cost of the battery and its accommodation, because the generating plant is perfectly able to carry the load put upon the battery, since by hypothesis, this load is a light one. Hence the machinery might be run all the time, in which case the battery would be entirely unnecessary and sufficient rest for the machinery could be secured by using different machines for the periods of light load on successive days. These statements are based upon the supposition that the battery is not used to help the dynamos at the time of maximum load, since this case will now be considered separately.

4. *Accumulators to aid in carrying the maximum load.*—If accumulators are substituted for a certain portion of the dynamo capacity, the question arises whether the substitution secures any advantage. In regard to first cost, authorities differ widely. These discrepancies probably arise from the confusion between K. W. and K. W. hour of output. Most accumulators have a normal time of discharge of about 10 hours, hence the cost per K. W.

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hour is only one-tenth of the cost per K. W. of output, and this would, of course, vary with any change in the time of discharge. In many cases it is specious and leads to mistakes, to speak of K. W. hours, to appreciate which fact we have only to realize that the K. W. hour capacity of a dynamo is almost infinite, since it might run for twenty years. The actual K. W. of output, or in short, how many lamps can be simultaneously fed, is the question in electric lighting. Moreover, in most cases, the time of discharge of an accumulator is unnecessarily long, and this is particularly true when it is used to help carry the heavy load which usually lasts only one or two hours. In this case the remaining hours of available discharge are of little or no use. If it be attempted to discharge more rapidly, both the capacity and efficiency are reduced, and in many types the condition and very life of the battery are injuriously affected by a high rate of discharge. What is needed for the maximum load or "peak of the load diagram" is an accumulator with a normal time of discharge of two or three hours and having a correspondingly smaller first cost, bulk and weight, that is, about one-quarter of those of the ordinary forms of battery, but certain types of cell are capable of discharging at this rate. It is evident that the time of charging need not be made as short as that of discharging, if it happens to be more convenient to charge less rapidly.

The use of accumulators to enable the machinery to be stopped, which is a case already discussed, usually demands a time of discharge of from 10 to 14 hours, which agrees quite well with the normal discharge rate of the ordinary forms of battery, but even then the time is unnecessarily long, since the average rate of discharge would rarely exceed one-half of the maximum rate. Consequently the battery would either be incompletely discharged, or the rate would have to be made excessive at certain times.

5. *Accumulators to maintain uniform load on the engines.*—Steam engines are very inefficient at light loads. This inefficiency, in fact, is one of the chief sources of loss in an electric lighting plant, and the principal object of the engineer who designs and operates a station should be to reduce this waste to a minimum. The accumulator is the most important means of accomplishing this result, although there are other methods such as gas, thermal (hot water) and steam storage, all of which have been carefully compared by Mr. Nelson W. Perry in a paper before the National Electric Light Association, February, 1895, "Storage of Energy Essential to Economy of Working Central Stations." Judicious selection of the number and sizes of the engines would enable them to be worked at a considerable fraction of their full capacity nearly all of the time, and it would seem that the same care that would be required to manage the battery might enable this to be accomplished. Nevertheless the accumulator gives more flexibility to the plant, and where introduced it often seems to considerably increase the

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economy of the engines by making their load more uniform and nearer their full capacity. According to the figures given by Mr. Perry in the paper cited above, an electrical horse power costs $48.68 per annum when developed steadily, and costs $117.78 per annum with a variable load similar to that of an electric light station, that is, the latter costs about 2.4 times as much as the former. This ratio seems very high, but is borne out by statistics[1] which give a very large coal consumption for most electric light stations.

Under these circumstances almost any method of making the engine loads more uniform, should increase the economy of working. Doubtless an accumulator would benefit any plant in which an engine runs for any considerable portion of the time at less than half of its full power.

If a plant is so small that it contains only one engine, it may be necessary to run it a great deal of the time far below its full load. But even with two engines it is generally possible to select the sizes so that the smaller one runs economically during the periods of light load, the larger one alone is suited to medium loads, and both are used for the maximum output, the times during which any engine is very much underloaded being very short. With a greater number of units, it becomes still easier to properly apportion the load, and when there are five or more engines as is usually the case in large stations, the loss from this cause should be trifling. To be sure the waste of energy which occurs from using boilers for variable loads still remains. but according to the figures given by Mr. Perry this is less than that due to the engines, and general experience shows this to be true.

6. *Accumulators used as transformers.*—If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage current will be required for charging and a low voltage current will be given out. The total amount of energy measured in watts is the same minus the loss of 15 or 20 per cent. which always occurs in accumulators. The result is similar to that obtained by an alternating current transformer or motor-dynamo. Such a method of transformation of potential might be employed in connection with long distance transmission of energy, the current being sent over the line at high voltage and converted to low voltage by accumulators for local distribution. For potentials of several thousand volts which are commonly employed in transmitting long distances, the number of cells required would be so great as to make this of doubtful practicability compared with the ordinary stationary or rotary transformers, but it would give uniformity in load and other advantages which may be secured by the storage of energy.

7. *Accumulators used for subdividing voltage.*—This application is similar in principle to the preceding. The most import-

1. See Report of Committee on Data to National Electric Light Association, *Electrical World*, March 2d, 1895, p. 273.

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ant practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery. This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a sub-station near the districts to be supplied, so that it is only necessary to run two conductors to that point instead of three. The same principle may be applied to the five-wire system.

8. *Accumulator sub-stations.*—The plan of installing battery plants at local centers which are charged from the main station, enables some of the conductors to be saved in a three or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps which may be several times the average value. This, of course, gives the same steady load on the generating machinery as if the battery were located near it.

The batteries at the various sub-stations may be connected and charged in series or in parallel. The former plan is similar to case 6 and would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this high difference of potential would exist between the first and the last batteries of the series, and if either of them became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage. This would demand that the maximum difference of potential should not exceed 500 volts, or, in other words, four batteries of 110 to 125 volts each, might be charged in series and could be connected to the lamp circuits at the same time. This would practically amount to a five-wire system using accumulators to subdivide the potential as explained in case 7. If the batteries were entirely disconnected from the lamp circuits while being charged, the latter would be free from danger of the high pressure which might therefore be 1,000 or 2,000 volts if desired, the batteries being charged during the day and supplying the lamps at night. For continuous working, two batteries would be necessary. Accumulator sub-stations not only save copper in the feeders but also reduce the cost of, and lost voltage in the distributing conductors because the batteries can be placed near the lamps to be supplied with current.

Accumulators used for two or more of the above named purposes.—Each of the different uses of the storage battery has been considered separately, to avoid the confusion with which this subject is often beset, but as a matter of fact the employment of the accumulator for several of these purposes is the most common

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practice. By thus combining these different applications, the plant may be rendered not only more economical but also much more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure owing to poor draught or other circumstances, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it for a few minutes to make some repair, adjustment or change of arrangement, connection, etc.

It is also possible to feed some of the circuits from the battery, while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways an accumulator may be a very convenient adjunct to an electric lighting system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all of the machinery but it probably would not affect the battery, and *vice versa* an accident to the latter is not likely to extend to the former.

Communication by Carl Hering on "Past and Present Obstacles in the Storage Battery Development."

The great and numerous advantages of a satisfactory electric storage battery have been described so often, and are so well recognized and admitted by the unbiased, that it seems unnecessary to again enumerate and discuss them here: The question which the engineer and constructor should discuss at present is not "Is a battery desirable?" but rather "Why is it that storage batteries seem to have been unsatisfactory?" and the question which concerns the capitalist is "Does it pay in dollars and cents to use the storage battery even if it is kept in a satisfactory condition by the makers?"

The latter question can be disposed of here in a few words. If the makers guarantee to keep the battery in a satisfactory condition for a certain rate per annum, or if they rent them, then it becomes a mere matter of calculation to find whether it pays or not; but this calculation must be made for each specific case, as the cost of the batteries and their maintenance seem at present to be such, that an estimate for a general case can hardly be considered conclusive, the margin being in many cases too small. In some specific cases it will be found to be decidedly cheaper, in some it will be doubtful, and in some, decidedly too expensive. Limiting ourselves to this country and judging in a gen-

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eral way from the number of storage battery installations. it would seem that the price at present (including of course the cost of maintenance) is such that in perhaps the majority of cases the margin of profit to the user is so small or so doubtful, that it does not balance the supposed risk. The commendable practice of renting, relieves the purchaser of this risk, which then leaves the question a mere matter of cost. A material reduction in the first cost and cost of maintenance, would therefore at once turn the tables in many cases so decidedly in favor of the storage battery, that there would be little doubt left as to the economy, and it would render the practice of renting unnecessary in most cases. Cheapness, therefore, is one of the most important points which affect the outlook of the storage battery.

To return to the first question "why is it that storage batteries seem to have been unsatisfactory" we must limit ourselves to this country, as probably thousands of tons are, and have been in successful use abroad. In Germany for instance, almost every one of the large continuous current central stations is equipped with a battery plant; in England they are used very largely for private plants, as also for central stations; an English firm recently claimed to have sold a total of "six miles" of accumulators placed in one continuous row, and a French firm is stated to make several tons a day.

The chief reason why so few storage battery plants exist in this country, seems to have been that the accumulator companies have for years been so busy fighting each other's patents and have spent so much money in this litigation, that they have had neither time or money left to manufacture and install their batteries. But all this litigation has now come to an end, thanks to an enterprising company which has bought up all the little life that is left of these historic "pasted plate" patents. This, together with the fact that it is now conceded by many authorities that for many if not most purposes the unpatented Planté type of cell is the better, removes the chief obstacle in the storage battery development in this country. The fact that the companies have been too busy with litigation to attend to legitimate business, has shaken the confidence of the public who naturally ask "where are your batteries in use," the only and unsatisfactory answer to which is "abroad." Much "missionary work" must first be done before public confidence will be restored, and let us hope that the recently started "rental" companies will soon accomplish this. It is up-hill work, but prospects at present seem bright and encouraging.

As the patent question has now been settled, and as cells of the Planté type have now been developed into practical forms, the storage battery outlook at present lies largely in the hands of the constructing engineer, and we should therefore look at the question from this standpoint.

The storage battery has for years had the reputation of being

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like a delicate, sickly baby, continually threatened with half-a-dozen diseases, and requiring the constant attendance of a trained nurse, besides the fatherly care and large purse of its manufacturer. To the user the five chief diseases of the accumulators appear to be: buckling, short-circuiting, sulphating, disintegration and dropping out of the peroxide. Many inventors have thought that most of these may be made uninjurious by a process of opposing or resisting their disastrous effects, as distinguished from preventing their occurrence, although the term "preventing" has incorrectly been used to describe it. Buckling has been opposed by main strength and sometimes awkwardness; short-circuiting by porous insulating sheets between the plates; falling out, by enclosing or locking the peroxide so that it cannot drop out, etc. Whether and how far such heroic methods have been successful can be determined only by tests, but it seems to the writer that many of the methods are like curing corns by cutting off one's feet; the cures may be effective, but can hardly be called satisfactory. To attempt to prevent the almost irresistible force of expansion of the peroxide from exercising itself, by confining the material in an inelastic lead frame, is a formidable and it seems, an almost hopeless task; the inevitable result is that one or the other must give way; if it is the peroxide, it will ultimately be crumbled by the pressure; if it is the lead, there will probably be buckling or at least a separating of the contact surfaces at the subsequent contraction of the peroxide, and this inevitably results in the formation of that very objectionable layer of white sulphate which practically insulates the active material from its conductor, the consequences of which are sure to be fatal. The development of the storage battery has been greatly retarded by the fact that it was in the hands of mechanical engineers instead of chemists.

The careful constructor should attack the problem in a different way; he should go back to the beginning to find out the prime causes, and then prevent, if possible, these causes from arising, rather than to attempt to oppose their effect by sheer force and awkwardness. These causes seem now to be understood, and the question therefore is how to prevent them. One way is to supply with each battery a printed and neatly framed long list of "don'ts" or limitations in the form of rules telling you what you must not do, with a foot note attached, saying, that the company's guarantee ceases if these rules are violated. This may be satisfactory to the company but certainly not to the user. A more satisfactory way would be to construct the plates, if possible, so that these prime causes of trouble cannot arise, no matter what mistakes the attendant may make, or what emergencies the battery may be called upon to meet—within reasonable limits of course. To discuss all these prime causes in detail would require writing a treatise on the subject, but they may be summarized briefly, and their prevention will then suggest itself.

The chief evil effects are apparently caused by too rapid charg-

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ing and discharging. With many of the favorite methods of avoiding the effects of high rates, the capacity and efficiency at such rates, both become so low that the user will be discouraged from discharging so fast, and the current will fall so rapidly that it will have little chance to do much mischief. Such methods are applicable only when rapid rates are never desired, but those cases are the exception, rapid rates, or at least a provision for them, being generally very desirable and often essential as in traction work for instance; such methods have therefore solved this problem only for a limited field. What should be done is to try to construct the plates so that they are adapted to high rates without a great loss of efficiency or capacity. It will be found that in the majority of cases in which the storage battery would be of special value, it is a question of *rate* rather than *capacity*, that is, a great horse power for a short time is more often required, than a large quantity of energy delivered at a slow rate; it seems from a number of cases, about which the writer has recently been consulted, that any capacity above that which is obtained at a one, two or three hour discharge is generally of comparatively little value.

To study the effects of rapid discharges it must be remembered that the acid is as important as the lead oxides; when its density falls too low there will be a lowering of the E. M. F.; Acid is withdrawn from the solution during discharge, hence the diluted acid in the fine pores of the active material must get out, and denser acid must get in; but the only force which does this is the difference between their specific gravities, and as this is very small, the force will be small and therefore the circulation will be slow, which in turn reduces the E. M. F. The chemical action will therefore be confined chiefly to the external surface, which is freely exposed to the acid, and the action then becomes so great per unit of surface, that white sulphating, or better, complete sulphating, takes place. If a rapid discharge is not to injure the plates nor lower the voltage by reason of the acid in the pores becoming too dilute, the circulation must be rapid; great porosity accomplishes this partly, but is attended by frailty and poor conductivity of the peroxide, which again results in a fall of the voltage. The ideal method would, therefore, seem to be a vertical lead plate to act as a good conductor with an extremely large surface and a very thin layer of peroxide on it, freely exposed to a large quantity of acid, which is capable of circulating rapidly. That such a plate may be made to have a greater capacity per pound of plate for rapid discharges and perhaps an equal one for slow discharges, as compared with the best thick, porous plates, has been shown by experiments. The great capacity is doubtless due to the fact that the active material is more completely utilized, as it is all close to the conductor and freely exposed to the acid. The capacity of such a plate will evidently be affected only slightly by the rate, and the loss of voltage and therefore the watt efficiency will depend more

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on the conductivity of the lead, than on the acid becoming too dilute in the immediate neighborhood of the active material. To obtain high rates accompanied by good efficiency and capacity, there is little doubt that the best way is to use large freely exposed surfaces, rather than to try to resist the evil effects of high rates, mechanically.

In rapid charging, the acid becomes too dense in the pores of a thick mass of active material if the circulation does not keep pace with the demand; this dense acid softens the peroxide and there is a tendency to form gases when the proper chemical action cannot keep pace with the current. Both the softening of the peroxide and the mechanical effects of the gases are injurious. What was said regarding porosity and the ideal plate applies therefore also to the charging.

The negative plates being soft and tough, are not so easily injured, but unless the acid can circulate very freely; there will still be a lowering of the voltage like with the positive plates, and probably also a lowering of the ampere-hour capacity.

The contact between the peroxide and its conductor must be very good, for, if poor, then a white sulphate forms at the surface, which practically produces an insulating layer and disastrous effects are then inevitable. The ideal contact is obtained when the peroxide is formed on the lead electrolytically, as in the Planté processes.

The peroxide will insist on expanding during the discharge, and on contracting during the charge. It would be much better to accept this as an inevitable fact than to try to keep the material from obeying the laws of nature by forcibly confining it within an inelastic frame, as many inventors have attempted to do; the results of such an attempt have already been described. To hold a large mass of active material firmly in contact with a lead conductor, when one expands and contracts, while the other does not, or expands without afterwards contracting again—is a difficult matter. The best solution seems to be, to have the active material in the form of an extremely thin layer over a large surface, and formed from the lead itself, as this increases its adhering properties. If such a layer can be made porous, and if the surface is made up of small facets, there will be little tendency to buckling or scaling.

The gradual washing away of the surface of the peroxide, and the slow peroxidation and consequent disintegration of the lead support, seem to be absolutely unavoidable. Until some preventive is found, if it ever will be, it seems wisest to accept the inevitable and acknowledge that the positive plates are perishable. To use any other metals or carbon, is out of the question; the addition of antimony to the lead seems to retard, but does not prevent peroxidation. The favorite method of trying to avoid the effects of disintegration, is to make the frames of the positive plates quite thick, thus prolonging their life. This, if not ac-

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companied by other disadvantages, may be satisfactory for stationary plants in which the great additional weight is no hindrance, the only objection to it being the cost of the metal, which is no small factor in the total cost of the plate. But such a method is certainly not satisfactory for cheap or portable cells, and the gradual washing away of the peroxide remains the same whether the frame is heavy or light, provided that the surface exposed to the liquid is the same.

But there is another way of meeting those unavoidable effects of use, which has recently been applied, and which seems to be a much more rational and effective solution of this vexed problem, at least when lightness and smaller first cost are desired. Instead of making the positive plates heavy and expensive, they may be made very light, cheap and easily replacable; their life may then be shorter, but the battery will be as good as new whenever these perishable parts have been renewed; their life is soon known to the user and he can then readily determine for himself how much he must allow for amortization. Anyone who has urged the use of accumulators will appreciate the great value of being able to satisfy the user as to the amortization factor. A purchaser will believe you if you admit that the life of the perishable parts will be comparatively short, but he will not believe you if you say it will be long, even if you are telling the truth. But such a method, to be successful, requires that the old plates and sludge can be converted at a small cost into new plates; this it seems can now be done, and the writer believes that this alone will have a very important bearing on the outlook of the storage battery, at least for portable cells as are required for traction and many other purposes, or for both portable and stationary plants if the first cost is an important factor. Such a method becomes practicable only when the chief factor in the cost of the plate is the material, the cost of labor and forming being small.

For stationary purposes, in which the only objection to the weight is the first cost of the lead, good storage batteries have been used abroad with success for some time, provided the rates of charge and discharge are kept low. Assuming that the same storage batteries may be made in this country as well, the question which affects the outlook here, is then only one of the cost. But neither abroad nor here, does there seem to be a battery in the market in which the weight has been sufficiently reduced, and the rate sufficiently increased, for a really successful traction battery, the success of which has been demonstrated beyond dispute. It is here assumed that to the public and to railway companies, traction batteries are not a demonstrated success until a traction company which has no affiliation with the accumulator makers, finds it to its own advantage to use them in preference to other systems. That accumulator traction is the ideal system has been repeatedly acknowledged by good authorities, and that this field for batteries is very large and perhaps larger than that for station-

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ary work, is likely. The large first cost and cost of maintenance of the overhead construction for trolley roads, the large power station required, and the threatened damages done by electrolysis, would doubtless turn the tables in favor of the storage battery for many long roads on which traffic is not too dense, and possibly also for many suburban steam roads.

It seems to the writer that the only batteries which have a promising outlook for this very trying work, are those which have a very large surface, very small depth of active material formed electrolytically, and a very free circulation of the acid. The lead frames should be made only thick enough for proper conduction, the batteries must be cheap in first cost, and the positive plates should be capable of being replaced comparatively frequently at small cost. They should be proportioned so that a discharge corresponds to one trip of the car—and only one. To claim as an advantage that a battery can run a car, say four trips, is mere deception, and to the intelligent engineer it is simply an admission that it can do no better. No one would think of carrying four relays of horses on a trailer of a horse car, and why should the equivalent be done with the storage battery unless it is that the battery can do no better, and that it cannot be discharged rapidly enough so that the capacity and weight may be reduced to that required to run only one trip. The ideal is certainly a single trip discharge. If the rate for a four-trip battery could be increased four times without materially affecting the capacity, its weight and capacity for a single trip discharge would evidently need be only one-fourth as great. The charging rate should also be equal in hours to the discharge rate, or else it will take a plant of more than two sets of batteries to a car.

These various ideals mentioned above would, have only a theoretical and not a practical interest, were it not for the fact that recent tests have shown that a near approach to them has apparently been reached; it is somewhat premature at present to say more until the results of the tests have been confirmed by practice.

The above discussion may be briefly summarized as follows: cessation of litigation and the development of the Planté type of cells, make the storage battery outlook in this country much brighter: the cost of a guaranteed storage battery seems in many cases to be too nearly equal to that of the direct generators to encourage their general adoption. A reduction in the cost would therefore open a large field, much larger than in proportion to the reduction; the renting of accumulators seems a commendable method for introducing them. Most of the diseases which storage batteries are subject to could be avoided or made much less disastrous by having large surfaces, small depths of active material and free circulation. The first cost would be reduced and the vexing question of the uncertain amortization, settled, by a light, short-lived, cheap positive plate and a cheap process of re-converting old into new positive plates. Storage batteries for slow

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discharges have been a success abroad; a very large additional field would be opened by a light, cheap, rapid-rate cell.

The objection to a plate with a thin layer of active material, is that it may not retain its charge as well as one with a thick layer or pellets, but in most cases in which rapid rates are desired or cannot be avoided, the small loss in standing is probably more than balanced by the fact that the plates are not injured by rapid rates. As a rule, long periods between charges go hand in hand with slow discharges and less objection to great weight, while short periods between charges, high rates of discharges and lightness, usually go together.

In conclusion the writer desires to take this opportunity to make the following recommendations in the interest of engineers who may have to calculate accumulator plants:

That rates of charge and discharge be designated in *hours* and fractions, the current (or for power purposes, the watts,) during that time being considered to be kept constant. There can then be no mistake as to what is meant, as this represents the time in hours during which a cell will continue to give a practically constant current before the voltage falls below its limit.

That efficiences and capacities be always accompanied by the corresponding rate in hours.

That in giving an efficiency it should always be stated whether it is for ampere-hours or for watt-hours.

That for portable batteries intended for power purposes, the capacity be given in watt-hours instead of ampere-hours and that the weight given be that of the complete cell ready for use, as distinguished from the weight of the plates alone.

THE PRESIDENT:—We have a communication from Mr. Reckenzaun who has had a good deal of experience in storage battery matters which the author will kindly read.

COMMUNICATION BY FREDERICK RECKENZAUN ON "PAST EXPERIENCE WITH STORAGE BATTERIES."

A discussion of the storage battery question by this INSTITUTE is so appropriate that I sincerely regret that notice thereof reached me only a few hours before the opening of the meeting, due to my absence in Europe whence I have just returned. Being thus able to make only a very brief contribution, couched in general terms, I wish first of all to heartily endorse Mr. Childs' communication. While it contains much that has often been pointed out, advocated and demonstrated in the past, the arguments brought out in favor of the storage battery will bear repetition in view of the fact that the majority of engineers in this country have hitherto persisted in neglecting to fairly entertain them.

On the other hand, it must be conceded that there was cause for this neglect. Storage battery manufacturers in this country

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concentrated their efforts rather upon the records of their selling departments than upon effecting lasting success for their products. The tendency was rather to show highest capacity and smallest weight and bulk, or at least to make claims for these features, regardless of the conditions to be met; and the selection of type, design of auxiliary devices, manner of installation and methods of operation were treated as if of secondary importance. Engineers and customers in general considered the price of storage batteries high, the manufacturers seemed to agree in that feeling and endeavored to economize in all that pertains to the outfit, to an extent which, as we know, proved detrimental all round. Through years of hard experience gathered by that policy, and contrary to the valuable suggestions offered by the work and success of our European colleagues, this state of affairs predominated until at last it is beginning to be recognized that no less skill, care, scrutiny and liberality is essential to success with the storage battery than with the construction, installation and operation of the plants it is to form an auxiliary of. The storage battery demands as much consideration as steam boilers, engines or the dynamos of an electric plant. It resents the assumption that it may be treated on a par with the coal bin as a storage arrangement.

European electrical engineers, who have long ago settled down to the placing of the storage battery in rank with other principal parts of an electric plant, and who are looking upon this country as being foremost in the quantitative application of electricity, wonder why we stayed so far behind them with the storage battery when all we needed to do was to copy from them and multiply. They have various types in successful use, and a number of manufacturing establishments are doing a substantial and prosperous business.

It may fairly be assumed, and the views which I gathered on the subject tend to bear out the assumption, that to the advantages offered by the storage battery, is to no small extent due the fact that direct current central stations continue to largely predominate over alternating current stations in Europe.

Mr. Childs very appropriately referred to the fallacy of taking the loss involved in the storage battery as the basis for the efficiency for the entire plant, where it only yields a portion of its output to the latter.

Such erroneous assumptions as this have helped to retard the progress of the storage battery here, but chief of all drawbacks unquestionably was the lack of durability, which, having now reached a much more satisfactory measure, should at last bring the success which we were so long looking for.

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Discussion.

Mr. Townsend Wolcott:—Mr. President, I would first of all like to say that Mr. Edgar's communication is very important from the fact that he tells us what has actually been done with the storage battery. That is just exactly what we wanted. Instead of saying that such and such things can be done with the storage batteries, he says such and such things have been done.

In regard to Mr. Perry's communication the point that I wished to raise was in connection with the gas engine. It seems to me extraordinarily good work for gas engines, this consumption of 15 feet of gas per horse-power hour. I heard of a gas engine that ran 17 feet, but I learned by inquiring around that it was not a very durable engine or one that could be relied upon. May I ask what make of engine that is?

Mr. Perry:—I think that all the manufacturers in this country will guarantee 15 cubic feet, but in actual practice from 17 to 20 or more are required. I have used 25 cubic feet of illuminating gas in my calculations.

Mr. Edgar:—I would like to answer the questions Dr. Crocker raised; but before doing that, I desire to call attention to the point he made in regard to charging accumulators in series. He probably referred to the Popp system in Paris, which I also investigated with considerable interest. If that system is used, it is impossible to charge and discharge at the same time, unless the local systems of distribution are entirely separate; so that it could not by any possibility be used as we use systems of distribution in this country. All our network is connected together, and if our batteries are to be charged in series, it would be necessary to have two entire sets. This seemed to me to be the principal drawback of the system there, and it prevented its extension. It is impossible to keep the circuits entirely free from grounds, and the results would be that one system would have one voltage as compared with the ground, and the next another, and the next another, and it might go up to two or three thousand volts.

In regard to the question he asked in respect to cost, I have not the slightest objection to giving exact figures which will show upon what I base my statement. In the old type of station it was usually customary to figure that the entire steam plant outside of the real estate and the buildings—by steam plant I mean the generating plant in general—cost from $50 to $60 a horse-power. With the new type, high economy plant, it costs from $90 to $100 a horse-power. In our own experience we find that almost exactly true. In regard to batteries, our first battery was put in to give out 1,650 amperes on each side of the system. A 650 horse-power generating set gives out 1,333 amperes on each side. This, as a steam plant, would have cost $65,000. Our contract was for $44,000, and there were enough incidentals probably to bring it up to $50,000. This included

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45 per cent. duty. I do not mean that if it was bought in this country it would cost the 45 per cent. less, for I understand that the cost of crude lead here is so much more, that part of it is eaten up irrespective of the question of duty. The second battery was double the size. That capacity would cost $130,000 if it had been a generating plant. Our contract was $64,000 for the battery. The former price included the switchboard, the latter did not; to that I add $25,000 to include switchboard and everything outside of the building. So that about $90,000 as compared with $130,000, and $50,000 as compared with $65,000 is the comparison I had in mind. I want to emphasize this one thing, and that is that we do not care anything about the kilowatt-hours of the battery for this particular comparison. Kilowatt-hours have to do with operating. Kilowatt maximum has to do with investment; and we put it in for investment purposes. That is to say, as I have already said, we can with the same amount of capital put in more apparatus by using storage batteries than we can without. Now, if such apparatus has a capacity large enough to do that work which actually exists, we can actually save money by equipping one-third of our stations with battery and two-thirds with steam. I do not mean to say that considering the question of kilowatt-hours in general, for traction purposes, or for all the incidental purposes, that batteries are of course not very much more expensive than steam plants and I tried to make this statement with particular reference to that special use of the battery.

Now, in regard to efficiency, our guaranteed efficiency is 75 per cent. I never have understood that a high rate of charge and discharge was going to interfere with the efficiency of the battery. It is undoubtedly going to cut down the capacity. With an hour-and a-half rate of discharge, the battery has only two-thirds of the capacity that it has at four, five and six hours discharge. The efficiency is the same, and I feel quite sure that the manufacturers claimed that we would get higher efficiency if we charged and discharged at maximum rates than if we did not. I personally know nothing about that, except what I am told.

There is another point that Dr. Crocker made, which appealed to me in exactly the opposite way from what it did to him, and that is the English practice of running a large number of small engines as compared with the German practice of using two or three very large ones. It was that particular thing that appealed to me for the value of the storage battery. When we realize that with the same type of engine, if you put in a 200 horse-power engine and one of 800 horse-power, you naturally get 10 per cent. better efficiency out of the large one, from the nature of its construction, and that the small engine is likely to run 15 to 18 hours a day; you will find that the inefficiency caused by the small engine is very much greater than the 25 per cent. battery inefficiency run for only two hours a day. So that

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the actual economy of these small engines running under the best possible conditions is less than the economy of the large engines run under the best possible conditions, and a storage battery of 75 per cent. efficiency.

Then in regard also to the question of guarantee, I know nothing about what the American company guarantees. I have never asked the question. Our guarantee was for six per cent. of the cost of the cells. On the $44,000 contract I think the cells were put in at about $29,000. In the $64,000 contract the cells were put in at $59,000, so we are paying six per cent. on $59,000 worth of investment. There was a clause in the contract that if an American company was established, this should be reduced to four per cent., because this was done in Germany. I was informed by the manufacturers abroad that they were always willing to give a guarantee of four per cent., but that at least 75 per cent. of their customers refused it on the ground that it cost them but three.

Mr. H. Ward Leonard:—There is one use for storage batteries which has not been touched upon particularly, and which to me is perhaps one of its best applications, and that is in connection with the regulation of the speed of the motor, such as would be required for the operation of, for instance, elevators or street cars, as giving an abundance of means of securing variable electromotive forces for various speeds, and for reversals of direction. The point about storage batteries which is often raised to explain why the progress has been rather slow in this country has been the patent litigation, but I look upon that as merely an excuse for the slow development of an article which has not had a demand sufficient to develop it. I do not believe that any really meritorious article has been in the electrical field thus far which has been retarded in its progress by litigation, and the progress of the litigation which we have seen in the case of incandescent lamps, systems of distribution and electric street cars, while it may have cost a great deal of money for the litigants, as it unquestionably has, I do not think has tended to retard the progress of development—rather the reverse. In the case of storage batteries, the demand has not existed and their use has not given success, and that is the sole reason for the fact that they have not been used. As regards the cost per kilowatt, which is very largely the essence of the question involving economy, it seems to me that the figures that I have seen quoted, which make a favorable showing for the storage battery, take the maximum rates of discharge for the batteries that it is deemed safe to operate them at, and have taken the horse-powers of the engine at one-quarter cut-off. Now I agree with Mr. Edgar that the question of development of power for the peak of the load is one which is largely independent of the economy of production as compared with that for a very large portion of the total load which is below the peak. But it seems to me that in mak-

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ing comparisons, we should consider the cost of the horse-power of steam generating machinery when operated at its maximum load, its maximum capacity, which will certainly be fifty per cent., without unduly straining any good boiler or engine above that for which it would have for the ordinary evaporations in the boiler, and a quarter cut-off in the engine, and I think that steam plants figured on that basis can unquestionably be installed for fifty dollars per kilowatt to-day, and ones which will be certainly more efficient in the production of a kilowatt than the development of a kilowatt by a storage battery, with the conversion losses and the lack of efficiency and capacity due to discharge at high rates. In that connection, I will say that it seems to me that it is unquestionable that there is a very marked difference in the efficiency—not only in the capacity, but in the efficiency—of the storage battery when discharging at high rates, and that a very large factor in the question of efficiency is the resistance of the battery, and the $C^2 R$ loss will certainly very rapidly increase with the rapid discharge. What I would like to find out, if we can, is: What is the cost per kilowatt, when the battery is discharging at the rate for which the manufacturers guarantee the six or ten per cent. depreciation which they have guaranteed, and the figures—although we have had figures that are on their face very convincing—do not give to me an explanation of the difference between the prices which we have been familiar with in the purchase of batteries and those which have been quoted. I have bought batteries and installed them almost every year since 1885, and I have never succeeded yet in buying a battery at a price approximating $50 per kilowatt, although, of course, I have not dealt in very large units, but I have received a discount from the list, which is as favorable as I think is given to customers in this country, because the instances that I had were ones in which the manufacturers were quite interested in seeing the applications made—I could not get the batteries at less than $180 per kilowatt when operated at the maximum rate at which they would make any guarantee. I think, that judging from the price list that we have in this country, it is impossible to expect to get batteries to compare in cost with steam plants, even when run at double the rate that they call the excessive rate of discharge, that is, even allowing that the battery shall be run at double the excessive rate. The cost of batteries, even those of the largest size—if I may judge from the prices of batteries of smaller sizes—would be at least $100 per kilowatt.

Now, one point as regards batteries in use in this country. It is a very familiar saying that we do not appreciate them over here; that they have been used abroad, and it is through a lack of interest in the matter, or a lack of appreciation of their points, that they have not been used here. But there is one thing which is very pertinent to my mind. I have been installing dynamos for a great many years, and I do not know one of them that I

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have installed that is not running perfectly successfully and economically to-day and in good condition. And, as I say, I have been installing batteries nearly every year also, and I do not know one battery that is running that I have installed. That may be because I installed it, but there may also be some influence due to the fact that it is a battery. One of the best remarks about a battery that I ever heard was made by Mr. Edison to me. He said that "the blamed thing was wet," and I think that expresses a great deal electrically.

Personally, I am desirous of saying nothing except what is favorable of the storage battery; but I think that my views as to its applicability, and the reasons for applying it, differ from some others. I do not think that the storage battery is likely to be installed, when considering the question of cost in the light in which I presented it, because of its economy over the steam plant in dollars and cents, but I do not think that that is the thing to be considered. I think that Mr. Edgar has expressed it very well, and we all of us know how it is of the utmost importance that the service from an electric central station shall be perfectly reliable, and that the light shall be perfectly uniform, and the question of cost of the battery to my mind, and its efficiency also, is quite of secondary importance—if by the use of the battery they obtain absolute reliability of service and perfect uniformity of the light, and cannot otherwise—and I think that the battery may be installed in a station with a net saving to the station, rather than to go without it, when viewed from this standpoint; while I do not believe in the actual saving in dollars and cents in our central stations in this country, with the character of load diagrams that we have.

The figures which Mr. Edgar gave, I should like to ask questions about, as I think I must have heard them wrong. If I understood him, he said that the cost of a single battery was $50,000, when he considered the additional features that were necessary to get it installed, and I understood him to say that the capacity of that battery was 1,650 amperes at the full voltage of outside wires—1,650 amperes on both sides; well, allowing 250 volts for the outside conductors, unless I have made some error in my hurried calculations, it would seem that that is about 400 kilowatts, and if so, that would be about $12 a kilowatt.

Mr. Edgar:—One hundred and twenty dollars.

Mr. Leonard:—One hundred and twenty dollars—well, that seems to correspond with my figures better than I thought it did. Since it is $120 a kilowatt, which quite agrees with my idea of the cost, I do not see why it is maintained that it is so much cheaper in first cost than a steam plant.

Mr. Edgar:—I would like to say, in answer to Mr. Leonard's statement, that I do not think our battery rated at 1,600 amperes has any less factor of safety than an engine with one-quarter cut off; that is to say, that the battery is supposed to run regularly

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1,600 amperes, and the engines that were put in at that cost are supposed to run regularly 400 kilowatts. It is possible that the engine would run double that. If you had dynamos that would run 800 kilowatts instead of 400, they would cost very nearly twice as much. There is no overloading of the dynamo to anything like the extent there is of the engine. The excess power of the boiler has already been discounted in its installation. On the other hand, the battery, although guaranteed for 1,600 amperes, is said to run 4,800 for fifteen or twenty minutes, if it has to, and I would not hesitate a moment to put that on if necessary. So I think the element of overloading in one, is about equal to what it is in the other.

Mr. Leonard:—The point which I should like to emphasize is that the guarantee has been upon a cost of $120. Of course, we all know that the batteries will give, with certain results, a very much larger rate of discharge. As to what these results will be, only the future can tell. But if they are worked at two or three times the maximum rate guaranteed by the makers, of course it is entirely at the risk of the owner of the battery, and I do not see any very good reason for supposing that they will act very differently from other batteries that have heretofore been overloaded. I do not quite agree with Mr. Edgar as to the fact that a dynamo cannot be operated during a period of half an hour or an hour, and at a very large amount beyond the amount for which it is guaranteed for continuous duty. It seems to me that in the case of large dynamos, the output could be very much increased for the matter of an hour or two without any detriment to the dynamo.

Mr. J. B. Entz:—I have recently spent a year in the factory of the Tudor company in Germany, and have had occasion to know what their practice is in that country and what their results have been. They have a great many large central stations which have been installed from ten to six years. The opinion of all engineers with whom I spoke on the subject were the same as those Mr. Edgar has expressed to-night. I have met engineers from Siemens & Halske and the Algemeine Electricitäts Gesellschaft, Schückert & Co., Oerlikon and other large companies, and whenever I started to criticise the battery in any way, they rebuked me by saying that it might be so in this country, but that the results were different there, and the results were very satisfactory. The company ships 60 tons of battery a day. In Hanover, where they have had an installation for six years, the efficiency was 83½ per cent. for the entire year's work, and the loss of energy but five per cent. of the total output. The company sells the batteries with the capacity specified for the different rates of discharge. The customer may discharge it in one hour, two hours or ten hours as he pleases, and it does not affect the guarantee. The purchaser has the option of taking the battery without any payment for guarantee for two years.

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The company keeps it in perfect repair for that time. At the end of two years the purchaser can take a guarantee from the company for four per cent. a year for ten years, but very few of them care to do that. The actual expense of maintenance has been two and a quarter per cent. to the company. In that time they made considerable money out of that four per cent guarantee.

Mr. J. R. Williams:—I would like to say that the efficiency of the battery, as Mr. Edgar stated, does not vary except within a very small fraction as the discharge rate increases; that is to say, a battery that would give a watt efficiency discharge at a ten-hour rate of 80 to 85 per cent, would still give a watt efficiency of 78 to 84 per cent if discharged at a two-hour or a one-hour rate. The capacity would decrease as the discharge rate increased. But if you take out a certain capacity at a high discharge rate, it would only require charging to the same extent as the amount of current that had been previously discharged.

Mr. J. Appleton:—There are one or two things about Mr. Perry's communication to which I would like to call your attention. He advocates the use of generators driven by gas engines for taking the peak of the load in central stations. Now in any station of a reasonable size this peak must be at least 400 horse-power. In order to take this with gas engines, it must be necessary at least to have two or more engines driving generators. I would like to ask Mr. Perry if he has tried to run dynamos in parallel with gas engines of that size. If he tried it once, I do not think he would be inclined to advocate it in this way. I notice Mr. Perry begins his communication by advocating the use of gas engines for electric lighting, and then goes on to say that he does not think there is a single case in this country where they have been successful. I think this must be due to the fact that he has never tried to use them in conjunction with storage batteries. The modern gas engine, as built in this country to-day, I do not think is very far behind the European gas engine. Germany is considered the home of the gas engine, but I think we are getting nearly as good results in this country now, as they are obtaining there. In fact, I know of many isolated plants which are working perfectly satisfactory with a combination of a gas engine and storage battery. Mr. Perry calls attention to the fact that in England, France and Germany a great many isolated plants and also central stations are using gas engines, but I venture to say that not five per cent. of the whole number are running without a storage battery in combination. Referring to his suggestion of transmitting power to outlying stations by means of gas through an iron pipe, even if the gas engine were available for taking the load in the outlying district during certain hours of the day, I think his calculations are wrong in one respect. He compares the price of the iron pipe to the price of copper mains.

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Now I take it that if he has his iron pipe, he must have his copper mains as well; and having his copper mains, he might just as well use them to transmit current to the outlying districts and charge the storage battery, raising the pressure by a booster.

With regard to the general use of the storage batteries in this country, I think the previous practice has been wrong in this respect. The individual conditions of each case have not been considered. When an engineer considers any particular installation, he looks to the conditions, and puts down his generating plant to suit those conditions, and it must be done in the same way with a storage battery. There are storage batteries built to-day for certain purposes which ought not to be discharged above a ten-hour rate. Then again there are storage batteries built to discharge at a half-hour rate, because for heavy work and for regulation a battery must be capable of discharging at a very heavy rate. With regard to the question of regulation, recently I have had occasion to figure on a problem where there was an output of about 2,000 horse-power from one station; it was a fluctuating load, resulting in a variation in voltage of about 20 per cent.; by the application of a battery which would give about 350 horse-power at a one-hour rate, it is possible to keep that fluctuation down to a total variation of two per cent., and I think that is nearly as close as most engineers want. A great many of the speakers, or some of them at least, have said that the previous storage battery plants have not been a success, and in connection with this there is one point, I think, which has been quite overlooked. A storage battery will not show signs of distress when it is very heavily overloaded. You take a case of a dynamo and battery working in parallel on a two or three wire system; say some extraordinary conditions arise on the circuit, such as a short circuit; the battery would take a very great deal more than its share of the load. The generators begin to kick at once. The battery will take all that is wanted; and it is this very fact of your being able to get out of a battery nearly everything you want, whether the battery is built to discharge at a high rate or not,—that has been the ruin of a great many batteries in previous years.

Mr. Chas. Blizard:—We do not recognize the company Mr. Perry so mysteriously describes as "the leading storage battery company of this country."

Through an oversight, unintentional no doubt, Mr. Perry does not quote from a letter under date of June 11th, 1894, sent him by this same "leading storage battery company" in which the matter of maintenance is dealt with as follows:

"We will undertake to maintain installations of our accumula-
"tors when operated at normal rates, upon a basis that will limit
"the cost of perpetual maintenance to 10 per cent. per annum,
"upon the original cost."

If Mr. Perry had brought his communication up to date, he

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might have quoted from the current edition of the catalogue issued by the storage battery company in question in regard to maintenance as follows:

"The company is prepared to undertake maintenance con-
"tracts under which they will guarantee that the total amount
"paid for renewals during the term of the contract, shall not ex-
"ceed 10 per cent. per annum on catalogue prices of the cells
"specified in the contract." The clause covering the return of the old material being omitted.

It is generally understood that retail prices are not maintained when wholesaling.

It is not a fact that the public has been led to understand by the battery company or its representatives that the guarantee offered means anything more or less than what is distinctly stated in the catalogue, and the fact that in the letter from which Mr. Perry quotes he was referred to the catalogue for terms of guarantee, is a sufficient refutation of his argument.

Mr. Perry's criticism would seem to cover the manufacturer who recommends the installation of a battery of capacity suitable to the work to be done, and who asks when giving a maintenance guarantee that the battery be worked within its normal limits and handled in accordance with the simple rules, which experience has proven, produce the best results as to efficiency and durability. I fail to see the injustice or hardship involved in these requirements.

Mr. Perry's statement that the guarantee holds good when the battery is cared for in exact accordance with the instructions laid down by the manufacturer, conveys the impression that an infraction of the rules would necessarily nullify the guarantee. While the selling company would undoubtedly have the right to withdraw, I do not know of a case in which such a course has been taken.

"The leading storage battery company of this country" does not anticipate that its business will be materially affected by Mr. Perry's alleged discovery of the difference between its nominal and actual guarantees.

Mr. Perry:—Replying to Mr. Appleton, I believe that he was right—that in most of the applications of the gas engine abroad, the storage battery is also used, as it is in connection with dynamos driven by steam engines. He speaks of the peak of the load requiring in the neighborhood of 400 horse-power. The largest gas engine so far constructed, so far as I know, single cylinder gas engine, is of 375 horse-power, with fuel gas; with illuminating gas it will go something over 400, perhaps 450 horse-power, and it has been repeatedly stated by English manufacturers that they were ready to make gas engines in 1,000 horse-power units whenever wanted. But it is customary, I understand, where the large units are employed, to use two-cylinder gas engines, so that we may have for instance an engine

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of two cylinders, each of which would separately give 200 horse-power, and the explosions are so timed as to give an explosion once every revolution. There is an advantage in that since it makes the angular velocity of the armature more regular. Then in regard to the transmission of power by means of gas to an outlying station, Mr. Appleton suggested that we have the copper mains also. My idea was to supplant the copper mains with the gas mains, and while I suggested a six-inch pipe, that was assuming that we required that power continuously. With the storage battery the claim is that we may use a smaller conductor, and by charging for a long time, we can store up a large amount of energy to use when the demand is excessive. The same would apply to gas storage. You have your gas-holder there, and instead of using a six-inch main to carry that energy that distance, you might use a very much smaller one, and charge your gas-holder during the day, or during the hours of light loads, and your expense of transmission would be still less, and the interest on investment would be still less; and the other object in transmitting by gas to outlying stations was that the efficiency of transmission would be very much greater, at a distance of two miles even, than if you used a transmission of a thousand volts, which I suppose would be about as high as it would be proper to transmit current for the storage of energy in storage batteries.

In regard to Mr. Blizard's remark, in reading a paper before the National Electric Light Association, at Cleveland, I was jumped on by a member of the leading storage battery company of this country for some of my remarks in regard to the storage battery at that time. He distinctly stated at that time, if I recollect his remarks, that the cost of maintenance, guaranteeed charges, was 10 per cent. on the *price* of the battery, and this letter that I referred to and the catalogue—the catalogue was the one in force at that time—contradicts that statement flatly. This is the first opportunity I have had of replying to it. I have seen a later catalogue since that, and this also bases the guarantee on the catalogue prices. I also have in my possession the letter to which Mr. Blizard referred, but which I have not copied here. That letter, as I recall it now, is less specific than this one—this one being very specific—as it states here: "We "send you by to-day's mail our illustrated catalogue, and would "especially call your attention to the question of maintenance, "as contained on page 11." That seemed to be very specific, as to what their guarantee means. Their guarantee was on the catalogue price and not on the cost price; and at that time and in that place it is stated that: "In all cases of renewal by con-"tract, the old material becomes the property of the company "and must be returned to their works free of charge for carriage "or packing." Now the omission of that statement from the new catalogue does not convince me that they do not expect that. I know from the experience of some others—not my own experi-

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ence—that when you ask for a battery for some particular purpose where the discharge is pretty rapid, or for some very unusual use, that the guarantee which they offer you, or that they print in their books, or that they talk about, no longer holds. They want a very much larger price for their battery, or their guarantee will be very much less favorable. And I admit that it is perfectly proper that they shall protect themselves; that that battery shall be used under certain conditions and in certain ways. They cannot guarantee a battery or a steam engine or anything else that is improperly used. But what I maintain is, that it is not economical under most conditions of central station practice, or at least where the demand is somewhat excessive in the way of discharge, to use the storage battery; that their prices are put up so high in order to give them a safe guarantee. Now there was a paper read at the Philadelphia meeting of the INSTITUTE, by Mr. Griscom, in which he stated that if you make your storage batteries large enough, the depreciation may be reduced to practically nothing. That we all know. So if you do make your storage batteries large enough, the company are perfectly safe in making you a guarantee of three per cent., or two per cent., or one per cent., if they choose; but your investment charges are very much larger under those conditions.

MR. E. T. BIRDSALL:—In regard to Mr. Perry's figures on the transmission of gas, he omits several important factors in the transmission of gas for that distance. In New York the subways are ventilated by pumping air through pipes, and they find that the loss of pressure per mile of 8-in. pipe, when delivering 12,000 cub.-ft. per hour, is 11 ounces per square inch. That is, starting with 16 ounces pressure, at the end of one mile the pressure is reduced to two ounces. That means, considerable power is used to pump that gas along, and that should be counted in the cost of transmission. Another factor is that the friction in the flow of gas in pipes depends greatly on the number of bends in the pipe; if it had a large number of bends or elbows, it would make a vast difference.

A third factor is the leakage factor. Every gas company in New York, except possibly the latest one, which has new mains, figured that the loss of leakage at the joints is about 10 per cent., and in that the loss of pressure in the electrical conductors is balanced at once.

In regard to the reason why batteries are not used more universally, it has always been my opinion, as the result of considerable experience, that all the first plants were too small for the work they had to do, and I will give two or three examples. One was a large private plant. A battery was put in, and it lasted six months under the use, and they put in a second one, about one-fourth larger, and that lasted about a year. The next one was about four times the size—that was about the time that I appeared on the scene—and that one lasted about three years, and

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now we are contemplating putting in one about eight times the size to do the work. In that connection, I might say that I just let a contract to-day to replace one of the plants that Mr. Leonard mentioned. This is due to no fault of Mr. Leonard's. I laid out the original plant—he merely installed it. The original plant was 300 ampere-hours capacity. and the plant that takes its place is 800 ampere-hours capacity. That is as big as I could get the man to buy. If I had my way, it would have been about 1,600 ampere-hours. Though that is an unusual case. They have electric heaters, and that I think explains the whole matter. But this has been the great difficulty; a man would put in a battery, and as a rule it will be about one-tenth of the size necessary to the work, and the battery would fail in six months, and all batteries were the same in his eyes after that. In regard to guarantees, it is my present practice not to call on the companies for guarantees where I am reasonably certain of having a chance to look after the plant once in a while. The only experience I had with guarantees was not successful—the company failed before we had a chance to call on them.

Mr. A. E. Childs:—Mr. Edgar in his remarks spoke of the value of his battery in cases of rapid changes of weather. I was in Boston one day in September, and I happened to be in an office taking light both from his company and from the alternating current company in that city. At three o'clock a very black cloud passed over the city, and inside of five minutes possibly every light in Boston that was ordinarily in use was turned on, and there is no doubt that inside of five minutes Mr. Edgar's station had on its maximum load. His lights were absolutely perfect; there was no diminution in voltage. The lights were steady without a single flicker. The lights in the adjoining office were low; they were like red-hot hair pins, and were flickering. The alternating current company's representative stated afterwards that they had not even had time to fire up their boilers or to warm their engines before the load was upon them, and, so suddenly did it come, that it was impossible for them to take care of it. In Mr. Edgar's case, his lights were kept up to the proper voltage He had the maximum load of his station thrown on without five minutes' notice. In three-quarters of an hour the cloud scattered, the sun came out, and the lights were turned off. Those who had used the Edison light in that case were highly satisfied, and those who had the alternating current light were complaining that it was from twenty to twenty-five minutes before they were able to see or read by their electric lights. Gentlemen, this seems to me of itself an exceedingly valuable use of the battery for the central station. If installed for no other purpose, it gives to the company using such a battery an argument in favor of the storage battery that cannot be gainsaid.

Referring to Mr. Hering's communication, we find that on page 613 he states that "a purchaser will believe you if you admit

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"that the life of the perishable parts will be comparatively short, "but he will not believe you if you say it will be long, even if "you are telling the truth." Later on he states that you may as well recognize that the life of a positive plate is short, and therefore you may as well build a battery that has a positive plate with a short life. His case seems to be like the case of electric meters in England, and the trouble which they had in introducing them. The original meters which were brought out were very scientific affairs, but the companies could not find people to use them. A happy thought occurred to one engineer to make the electric meters look as much like gas meters as possible, because the people were accustomed to seeing gas meters, and now it is an acknowledged fact that those meters which look like gas meters have a larger use in England than those meters which have special dial faces. Therefore it seems to me that Mr. Hering is working to satisfy the popular demand. He wants to produce a battery which has a short life, so that when he goes to a man and tells him he has a battery with a short life, that he will be believed. He does not want to produce a battery with a long life, for he is afraid people will not believe him when he brings it forward.

On page 614 he goes on to relate that his ideal car is one which has a battery which will run only one trip. I would like to ask Mr. Hering what he means by one trip. It may be one mile, or it may be 20 miles, or it may be 50 miles. What is he going to do with his battery when he has a 50-mile trip to make, before he has an opportunity of renewing it? And he goes on to state with a dash of humor that it would be rather a curious thing to see half-a-dozen horses carried on a trailer behind a street car in order that they may be used as relays when the first horses get tired out. At first reading we almost fail to realize the keenness of his wit.

Mr. Perry states that he would not recommend storage batteries under any circumstances, but that he has a still more economical method, and he proposes to use the gas engine for a purpose for which none of us, I may venture to say, have ever seen it used before, and he states in the most positive language that it is a more economical method. I would ask him to refer to even one central station using gas engines to take the peak of their load.

Referring to his remarks on the guarantee which he describes here, of June, 1894, Mr. President, the world has progressed a great deal in the last eighteen months, and if Mr. Perry, knowing that his communication was to be read to-night, had taken the trouble to inquire what guarantees he could obtain *to-day* and *not last June* twelve-month, he would be able to find that the companies supplying batteries could guarantee to him a specific percentage depreciation on the cost of the elements, and not on the complete plant installed. He would be able to find that the rate at which the depreciation goes on was guaranteed to be very

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small. It is astonishing, sir, to me at least, that a man will bring forward such statements as those, 16 or 18 months behind time.

In conclusion, I would state that the storage battery seems to call forth from engineers more prejudice than any other class of apparatus. It is my experience that certain engineers will tell you inside of 15 seconds, if you broach the subject to them, that they know all about storage batteries; that they do not want them at all, at any price; that they wouldn't have them if you gave them to them. If you put up a guarantee with government bonds at the back of it, they would not look at it. It seems to me, sir, that we must request engineers to show that spirit of enterprise, that spirit of investigation which they show regarding other classes of apparatus. We ought to expect from them that same spirit with regard to storage batteries, and that when they are approached on the subject of applying storage batteries to their central stations that they ought to take the matter in a spirit of investigation; and I am not wrong in saying that at present a large majority of them will not even consider the storage battery. They think they know all about it, and they think they know it would be of no use to them.

Mr. Carl Hering:—Mr. Childs asks what is meant by one trip; one trip is the distance that a car travels from one power house to another or back to the first. I did not think the term required any explanation.

Mr. Childs:—May I be allowed to ask Mr. Hering what the length of his trip is? That is the point I want to bring out. It varies considerably with different street car systems.

Mr. Hering:—The length of a trip, of course, may vary very greatly. What I wished to emphasize in the paper was that the best possible arrangement of a plant would be to use a battery which will discharge in one trip, whatever the length of that trip may be; whether the trip is one of a few miles or of a hundred miles, the battery should be adapted to it. As a rule, the trips of a car in an ordinary city are comparatively short, much shorter in time than what would correspond to the "excessive" rate (four hours) of discharge of a certain well known accumulator; there are very few cars in use the length of whose trips, in time, is four hours or more.

Mr. Childs furthermore said something about my suggestion that it might be better to make cheap short-lived positives than expensive long-lived ones. My remarks, of course, apply chiefly to plates which deteriorate; if one installs a much larger battery than one which has just the right capacity, and discharges it at very low rates, the deterioration will be very small. But, as stated in my communication, I referred more particularly to rapid discharge batteries in which the deterioration, as one of the previous speakers has shown us, is very great; and in those cases I think

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a cheap short-lived plate would be much better than one which is expensive and is intended to have a long life, but has not.

Mr. Childs in his paper states that the cost of a kilowatt-hour of battery is $37 to $40. Now, such a statement is very indefinite, and is of the kind which has misled so many. The statement is not complete unless the *rate* is also given, for it is very evident that if that accumulator would be discharged in one hour, the cost per available kilowatt-hour would be more than $37 or $40, showing that the *rate* ought to be given in connection with such a statement. I presume he meant that a ten-hour rate was understood; this means that a battery which will give a kilowatt (as distinguished from an kilowatt-hour) for ten hours costs ten times $37 or $40. If it is discharged at a higher rate than 10 hours, the cost per horse-power or kilowatt increases very much. Taking the catalogue of the company which he mentions, I find that for a four-hour rate the price per useful horse-power or kilowatt hour is increased about 25 per cent.; in other words, if you want a horse-power hour at a four-hour rate, it will cost 25 per cent. more than if you want it at a ten-hour rate.

Mr. Childs mentions an ampere-hour efficiency of 96.1 per cent.; that is very high, and I think it ought to be accompanied by a more explicit statement of how that efficiency was obtained. An efficiency, if it is as high as that, ought to be obtained by repeated successive discharges; or in other words, to be sure that the efficiency is correct, the accumulator ought to be discharged at least three or four times under exactly the same conditions. If it then gives an efficiency of 96.1 per cent. each time, the figure is correct; but unless it was discharged several times in succession under the same conditions, the figure which he gives can hardly be depended upon.

Mr. J. W. Lieb, Jr:—Several of the speakers this evening have referred incidentally to one of the uses of a storage battery, to which I think more importance should be attached. With the constantly increasing application of electricity, particularly as a motive power, the conditions to be met by systems distributing electric current from a central station are becoming more difficult. This is particularly the case in residential districts where electric elevators, which are being introduced at a rapid rate, produce sudden and large fluctuations in the demand for current, at times when the steady lighting load is light. This variation of current demand causes fluctuations of the E. M. F. in the customers' service, dependent in extent upon the amount and distribution of the copper in the system of conductors, the proportion of steady to fluctuating load, and upon the dynamo capacity supplying current at the moment. The average demand for current during the hours of daylight in residential districts being light, the generating units supplying current must necessarily have proportionately small capacity, if they are to be operated economically. Under such conditions generating

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capacity proportioned to carrying the average load when subjected to additional fluctuating loads, due to the inrush and accelerating current of starting elevators, would give rise to considerable variations in E. M. F. at the 'bus bars, and unsatisfactory lighting service. The addition of a storage battery is the effective remedy for such cases; a relatively small battery capacity taking up large fluctuations with but little fall in the 'bus pressure and with increased plant efficiency. The upper section of New York City, supplied from the mains of the Edison Electric Illuminating Company, is essentially residential in character, and since the beginning of 1893 the Edison company has had in continuous operation at its 53rd street station, a Crompton-Howell storage battery of a capacity of 2,000 ampere-hours, which in addition to other duties has most satisfactorily fulfilled the functions of a pressure equalizer as above outlined. Its effect upon the system is to reduce variations in the 'bus pressure to but $\frac{1}{3}$ to $\frac{1}{4}$ of what they would be with dynamo capacity alone in operation. Mr. Hering in his communication refers to the part which the chemist and the mechanical engineer have had in the development of the storage battery. I beg to differ with his unfavorable criticism of the work of the mechanical engineer in this connection, my own experience with many different types of batteries both in Europe and this country leading me to exactly the opposite conclusion. It appears to me that the lack of careful consideration of constructive details and substantial mechanical construction has contributed more largely to the failure of storage batteries in the past than lack of appreciation of the labors of the chemist. The wrapping of the plates in flannel, felt, asbestos, and similar materials, holding the plates together by rubber bands and similar devices, poor contacts at the electrical connections, lack of proper support for the plates, insufficient space between the bottom of the plates and the bottom of the tanks, and inadequate provision to prevent positive and negative plates from touching; these certainly are defects of mechanical construction. Yet how many failures could be directly traced to them. A statement of the important improvements that have been made in the construction of storage batteries within the past few years would, I think, show clearly a very substantial progress in all the details of mechanical construction. As much can hardly be said of the progressive work of the chemist in this direction, whose many investigations of the reactions involved in the electrolytic processes while of undoubted value have not developed any radical departures, while the tendency has been to revert to primitive types more substantial in construction and more carefully worked out in their mechanical details.

MR. CHILDS:—May I answer one point raised by Mr. Hering?

THE PRESIDENT:—Very briefly, Mr. Childs.

MR. CHILDS:—He referred to the increased cost of batteries

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on the ten-hour basis. I would call attention to the fact, that a battery working at a ten-hour rate is much cheaper per kilowatt-hour than a battery working at a two- or three-hour rate, and if Mr. Hering will take the trouble to examine any of the published price lists, he will very readily be able to calculate the scale on which the cost is graduated.

Mr. Leonard:—I would like the privilege of answering one point which it seems to me is of the greatest importance, and that is this question of efficiency and high rates of discharge. As a matter of fact, a cell which I am thoroughly familiar with and have tested, has a resistance of a thousandth of an ohm and its discharge rate nominally is 25 amperes. To operate that under the conditions where a storage battery would show its greatest advantage, that is a rate of 125 amperes, so that it could be discharged in about an hour and a half, the figures would have to be about as follows:—The capacity of the cells is 25 amperes at two volts. The $C^2 R$ watts lost when discharging at 25 amperes would be six-tenths of one watt, and the $C^2 R$ watts lost when discharging at the rate of 125 amperes would be 15 watts.

The President:—I think, as it is 11 o'clock, we had better adjourn. We are all very much obliged, I know, to the members of the Institute who have given the results of their experience, although that is a matter to be expected, as every member is supposed to tell everything he knows. But to Mr. Edgar, who unfortunately for us is not a member, I think we owe our very sincere thanks for the very clear and important communication he presented here to-night. A motion to adjourn is in order.

[Adjourned.]

Communicated After Adjournment by Nelson W. Perry.

The lateness of the hour and the very proper adjournment of the meeting prevented my replying at the time to several of the last speakers, whose remarks seemed to require a reply.

Mr. Birdsall questions my figures on the economy of gas transmission, citing the loss in head of the ventilating currents in the electrical subways, which he states as a drop from six to eight inches initial, to about one-half inch at a distance of two miles. These figures may be correct; but he must remember that the figures I gave were for a six-inch pipe that was free from obstructions, while he is citing two and one-half or three inch pipes which are more or less filled with conductors, offering an enormously greater frictional surface, and that these pipes open into manholes usually at intervals not exceeding 400 feet where eddy currents and leakage through the covers become important factors, and further that he is discussing air with a specific gravity of 1, and I illuminating gas with a specific gravity of, say, .45.

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To show the effect of increased specific gravity, taking a large pipe, 12 inches in diameter and 3,100 yards long, we find that a discharge of 65,000 cubic feet at .4 specific gravity is reduced to 49,000 cubic feet at .7 specific gravity, and to 43,000 cubic feet at 1 specific gravity. He is correct in regard to elbows. My figures were for straight pipes. The effect of elbows is to increase the drop, the latter being also a function of the velocity. With ordinary velocities and a 90° elbow having a radius two and one-half times the diameter of the pipe, the following drops (in inches of water-pressure) have been calculated:—

Velocity of gas in feet per second.	Back pressure, caused by one bend, inches.
4	.0015.
6	.00386.
8	.00598.
10	.00934.
12	.0135.
14	.0183.
16	.0239.
18	.0303.
20	.0374.
30	.0841.
40	.149.
50	.233.

So that unless the velocity is very high, it requires a large number of bends of this kind to make a material drop in line.

To show the relative effects of bends, and the specific gravity of the gas in the illustration cited, viz: delivery of gas through a six-inch pipe under four-inch pressure at a distance of 10,500 feet, I find, by calculation, that the velocity of the gas in a straight pipe would be 8.3 ft. per second and the amount delivered would be 6,000 cubic feet per hour. To deliver the same amount with one 90° bend would require a pressure of 4.00598 inches, and with 10 bends 4.0598 inches. Or to express it in another way, the introduction of 10 bends would cut down the amount delivered from 6,000 cubic feet to 5,955 cubic feet, the pressure remaining at four inches of water. The pressure exerted by four inches of water is but 0.143 lbs. per square inch. It will thus be seen that an increase in specific gravity is more controlling than elbows in gas distribution, but that both of them may be overcome by an insignificant increment in the energy applied to transmission.

As regards leakage, there is no question that in some cases the leakage from gas mains reaches as high as 10 per cent. per mile, but a gas engineer who to-day would lay down a line of pipe that would leak to that extent, would be received by his brethren with about the same *eclat* as would the electrical engineer who would construct an electrical circuit that leaked to the same extent. I believe it to be a fact, that it is easier and cheaper to prevent leakage of gas at the pressures ordinarily used, than it is to prevent electrical leakage at customary voltages.

Mr. Childs quotes me as saying that I would not recommend storage batteries under any circumstances, which is correct as far

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as it goes, but he omits the qualifications under which this was said, viz.: "There are some situations in which either convenience or extreme steadiness of current may be controlling, but "*where the question is purely one of economy*, I would not," etc. I think he will find it extremely difficult to prove that what I have said as to economy is not strictly true—so true, that it might be in many cases actually more economical as well as convenient to use storage batteries with gas engines, than to use steam engines without them,—the greater economy of the gas engine more than overbalancing the greater interest charges and losses in transmission and in battery by present methods. He knocks my argument all to pieces, however, by the profound statement that he "ventures to say that none of us have ever seen a gas engine used for this purpose before." Of course, if Mr. Childs "ventures to say" this, gas engines never have been so used. Mr. Childs, however, asks me to mention a central station using gas engines to take the peak of the load, and I will refer him to the Danbury and Bethel Gas and Electric Light Co.'s plant at Danbury, Ct. This is a small station, employing three 100 H. P. (nominal) gas engines, one of which is held in reserve. A series of five eight-hour Prony brake tests of the engines by Messrs. McDonald, Braine and Merritt, Jr.,[1] showed the production of an indicated H. P. on a consumption of 1.8 lbs. of coal. This is, I think, an exceedingly good showing for a station of this size, operated by units so totally unfit for the purpose, but by no means what it should be. The gas generator produced only 40 cubic feet of gas per lb. of coal, whereas it should have produced about double this of gas of a considerably higher calorific power. The mechanical efficiency of the engines, as given by Mr. Burchard,[2] averaged 87.31 per cent, and the thermal efficiency per indicated H. P. 18.61 per cent., and per brake H. P. 16.25 per cent. It is not a very rash assumption to say that had a more efficient fuel gas process been used, and the sizes of the units been better adapted to meet the load line, the K. W. output per lb. of fuel of this station, which for 182 days only averaged 435 K. W. hours per day, would have compared favorably with the best that has been reported to the National Electric Light Association. This was from a station having a daily output of nearly 23,000 K. W. hours, suspected by some to be Mr. Edgar's station at Boston.

I am placed in a somewhat awkward dilemma by the combined remarks of Messrs. Blizard and Childs, in regard to the letters from which I quoted, and from which I did not quote. Mr. Childs takes me to task for quoting a letter of such ancient date as June 18th, 1894, and Mr. Blizard takes me to task for not quoting one of still more ancient date, viz., June 11, 1894.

According to storage battery men, the storage battery is mak-

1. *The Stevens Indicator*, July, 1894.

2. Paper before Society Mechanical Engineers, April 10, 1895, by Anson W. Burchard.

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ing such phenomenal progress, that the layman (and by layman I mean everybody, electrical engineers included, who are not professional storage battery promoters) can not keep up with it. If we make any statement as to the performance of the storage battery, they say, "Well, yes, but that was yesterday; you ought to *write* to us, however, and find out what we are doing to-day." It may strike some as being a little strange that when they are on their feet telling us to write for information, they do not give us the information then and there, but they never do.

As illustrating the great and rapid progress in the perfection of the storage battery, I would point to the two letters from the president of the company. In the letter of June 11th he wrote: "We will undertake to maintain the installation — — — on a "basis that will limit the cost of perpetual maintenance to 10 "per cent. per annum on original cost."

Within one week the battery had been so far improved that the president was enabled to write on June 18 that they would guarantee it for 10 per cent. per annum on the *list price*, provided we packed and sent back to the factory, at our own expense, the old plates.

Last February I estimated the cost of storage batteries at $35 per H. P. hour. Mr. Herbert Lloyd, General Manager of the company, corrected me by saying,[1] that my figures were 50 per cent. too high. If that were so, then the price at that time was $22.33, and the perfection of the processes of manufacture has increased during the nine months just passed so far, that they are to-day able to sell batteries, according to Mr. Childs, at from $37 to $40 per K. W. hour, which is equivalent to $27.75 to $30 per H. P. hour. There is nothing like numerical examples to fix upon the mind incomprehensible magnitudes. But why do storage battery authorities persist in confining their estimates of cost to K. W. or H. P. hours? Why do they carefully avoid kilowatts and horse-powers? Certainly not because they can quote K. W. hours at $37 to $40, and would have to quote kilowatts at $120, for that would be misleading. But in order that we may make a comparison of the relative investment charges, will Mr. Childs tell us what would be a fair figure upon which to base an estimate for a dynamo per K. W. hour capacity?

Considerable was said at the meeting about the lack of appreciation among engineers of the storage battery. Some speakers assigned one cause, and some another; but I think Abraham Lincoln came nearer to it than any of them in his account of a certain steamboat on the Mississippi. He said that it had such a little boiler and such a big whistle, that it had to stop to whistle.

May it not be that the reason the storage battery has not made more progress in this country is that its boiler is small and its whistle is big, and that it has been whistling too much?

1. *Transactions* Nat. Elec. Light Ass'n, 1895, and all of the electrical journals, both American and English.

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Discussion at Chicago.

A meeting of the Western members was held in room 1737 Monadnock Block on Wednesday evening, November 20. There were present about 20 members and 12 visitors. Prof. H. S. Carhart was elected Chairman for the evening. The discussion of "Storage Battery Applications" was opened by Messrs. Arnold and Abbott, who read specially prepared communications. The communications presented at New York were referred to, but not read.

Communication by Arthur V. Abbott and Franz J. Dommerque on "Accumulator Economics."

It is true that the Europeans have made quite a large number of installations of cells, and with good success, but in this country this has not been the case as far as lighting is concerned. In the telephone service we have made of late rather an interesting application of small cells. It is in that service which formerly operated all the subscribers' transmitters at the various stations in the city by means of primary cells. A little more than a year ago it occurred to us to replace the primary cells by a small storage cell, charging the same continuously from the main office, excepting at the time when the subscriber was using the telephone in conversation. When the receiver is taken off the hook, the charging circuit opens, stopping the charging current for the time being, and allowing the local storage cell to discharge quite rapidly through the subscriber's transmitter for the purpose of conversation. Our installation has not been in service long enough to pronounce a conclusive opinion upon it as to the durability of cells of this kind. It is certainly very gratifying as far as it has gone. We have found that the maintenance of the local storage cell is less than that of the local batteries. As to whether the plates of the cell will last as long as we hope for, is a matter that future experience only can settle. In instances where the operation has been carefully made, and the installation properly and carefully attended to, we see no signs of deterioration in the plates. They seem as good to-day as they were 15 or 18 months ago. In cases of carelessness, either on the part of the manufacturer, or on the part of the users of the cells, it is unreasonable to expect that the cells will not suffer deterioration.

This, we regret to say, is the limit of our individual experience with the *durability* of storage cells. We feel that there is no question at all that they are a vast improvement, both from a service standpoint and from an economical standpoint, over the primary cell.

In the following we have taken what is perhaps a well-worn theme, and that is, the advisability, or, rather, an instance of the advisability of storage battery installation by comparing the cost

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of an electric lighting plant capable of supplying the entire city of London, as indicated by this diagram, which was taken a little over a year ago, with a steam plant alone, or with a steam plant with accumulator-regulation.

In the electrical installations, whether they may be for lighting or for power distribution, electricians have been seriously hampered so far, due to the fact that their station must be sufficient to supply the maximum demand that can be put upon it. We have no form of reserve. In gas works the retort plant may be comparatively small and run 24 hours for 365 days in the year. The break of gas in the holders is reasonably inexplosive, and in the holders we may store up 22 hours out of the 24, the breaks of the retorts to it use the other two hours. With water power we may build a dam, and the stream flowing into it may increase the reservoir capacity all night long, although the wheel turns but eight hours out of the 24. In other forms of manufacture we are able to store up a sufficient quantity of material for a sudden or unusual demand during a short period; but in electrical installation this cannot be done. The demand, as indicated in the diagram, is exhaustive between, say, 4 and 7 P. M. During that time the current rises to 11,600 kilowatts. During the other 21 or 22 hours of the day it is a comparatively small demand.

There have been in Europe a good many plants that have adopted storage cells for the purpose of equalizing the load line, and for the purpose of reducing the investment and size of the steam plant.

The European installations have, as far as we know, been uniformly successful. Why it is that they have not been introduced into this country to a greater extent, we are not aware. With the exception of the Edison company, there have been almost no installations of that character.

The European engineers have investigated load diagrams thoroughly and succeeded in cutting off the peak. How did they do it? Simply by developing accumulators. They brought it down to such a point that, for instance, in the Hanover station, the accumulators are kept in perfect order by the manufacturers, for the consideration of four per cent. on the original cost, for ten years, and are handed to the city at the end of the ten years in first-class service condition, the efficiency of the accumulators being 96 per cent. in ampere hours, or 78.4 per cent. in watt hours.

In order to give an idea of the ratio of capital expended on accumulators, to capital expended on the rest of plant, the rating of the property as it stood at the end of the year 1893–1894 may be written down.

Lot and building	628,075.71	marks.
Machinery	296,023.28	"
Accumulators	125,000.00	"
Line	538,866.87	"
Water facilities	44,968.01	"

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Tools, instruments and furniture	29,489.80	marks.
Electricity meters	60,600.89	"
Street lighting	15,758.07	"
Stores	16,489.4	"
Miscellaneous	13,439.64	"
Interest and stock market loss	128,634 08	"

In the case of Dusseldorf, the accumulators range higher yet, while the total installation cost is put down at 2,260,000 marks. The accumulators alone are credited with 280,000 marks.

Fig. 1 shows the combined output of the whole London central stations during the 24 hours ending at 6 A. M. on the 20th of December, 1894.

The correct level to base the calculation upon, is the day of highest load, and it will not be far out to choose the diagram of the 20th of December for this purpose.

The load curve shows a maximum load of 11,600 kilowatts, or

$$\frac{11,600,000}{740} = 15,700 \text{ H. P.},$$

and a minimum load of 800 K. W. equals

$$\frac{800,000}{740} = 1,080 \text{ H. P.},$$

the load factor being 33 per cent.

First, it may be ascertained what would be the expense if regulation was performed by shutting down part of the plant; afterward the expense with accumulator regulation will be calculated, and the comparison between the two obtained values will be the decision as to which system of regulation is preferable. In the first instance the plant has to be fitted up with machinery capable of supplying the demand at maximum load = 15,700 H. P. From the load diagram it will be seen that during about 14 hours, the load does not exceed 3,000 H. P. to any extent. This is of great importance for the choice of units. Choosing five units at 3,000 H. P. each, would take care of the maximum load also, as for a very short time during the day the engines and dynamos could be overloaded a trifle; the necessity of doing this would only occur in a few winter days anyhow.

The items required to determine the expenses would be:

Cost of fuel per year.

Cost of labor.

Cost of supplies and repairs.

Interest and depreciation on plant.

It has been ascertained by Mr. Fritsche that the average load throughout the year is 16.375 per cent. of the maximum load, hence,

$$.6 \times \frac{15,700 \times 16.375}{100} = 1,543 \text{ H. P. per hour},$$

or,

$$1,543 \times 24 \times 365 = 13,513,180 \text{ H. P. per year};$$

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the amount of coal used per H. P. hour being about $1\frac{1}{2}$ lbs. For such large units as are used in this case, it would require 13,513,180 $\times$ $1\frac{1}{2}$ lbs. per year, but to maintain banked fires, when part of the boilers are shut down, and bring the fires to average working condition again, an allowance should be made, which in the present case, where 3,000 H. P. is always required, does not amount to very much. Assume an addition of 20 per cent. on the 3,000 H. P. for the 14 hours, or 600 $\times$ 14 $\times$ 365 = 3,066,000 H. P. hours per year. The total H. P. hours would equal 13,513,180 + 3,066,000 = 16,579,180 H. P. per year, and the amount of coal used would equal 16,579,180 $\times$ $1\frac{1}{2}$ = 24,868,770 lbs., or 12,435 tons (of 2,000 lbs.). The price of coal per ton may be taken at $2.25, then the cost of fuel per year equals 12,435 $\times$ 2.25 = $28,000 in round numbers.

The cost of labor is determined as follows: One attendant is required per unit, or five in all, at 25 cents per hour, equals an expense per hour of $1.25. Ten firemen and two helpers at the same rate, or an outlay of $3.00 per hour. This fixes the cost of labor at $4.25 per hour. Add for superintendence $1.50 per hour, obtaining a total of $5.75 per hour, or $5.75 $\times$ 8,760 = $50,370 per year.

Cost of supplies and repairs is found, applying Dr. Emery's results obtained from the cotton mills of Fall River, as 13,513,180 $\times$ $0.0008 = $10,810 in round numbers.

It remains yet to determine the interest and depreciation.

Money is obtainable at five per cent., and the amount necessary to provide for depreciation should not be any more; therefore 10 per cent. is assumed. The cost of steam plant, taken at $64 per H. P. (Emery's value) + $\frac{1}{8}$ surplus power, a plant of

$$15{,}700 + \frac{15{,}700}{8}$$

equals in round numbers 17,700 H. P., as required which will cost 17,700 $\times$ 64 = $1,132,800, 10 per cent. of which is $113,280. The cost of dynamo, switchboard and accessories may be taken at $35 per K. W., or $25.90 per H. P.

The cost of 15,700 H. P. will be 15,700 $\times$ 25.90 = $395,000, the interest and depreciation of which, on the basis of 10 per cent., will amount to $39,500.

The total expense, therefore, per year will be $28,000 + 50,370 + 10,810 + 113,280 + 39,500 = $241,960 for regulation by shutting down part of the plant.

To calculate the expense for accumulator regulation, the load diagram has to be studied. The kilowatts found by integrating the area below the load curve gives the watt hours to be delivered to the line; this is found to be 100,800,000 watt hours. The engines in this case have to generate an additional amount to make up for the loss in the accumulators. The total amount may be designated for the present by x watt hours; x watt hours

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may have to be supplied by the accumulators, and z watt hours by the dynamos in 24 hours; z may be the effect to be produced by the dynamos in watts. If the efficiency of the accumulators is taken as 75 per cent. (which is not too high by European experience), $\frac{100}{75}y$ or $1\frac{1}{3}y$ have to be given to the accumulators to enable them to give y to the line, hence $\frac{1}{3}y$ is lost in the accumulators: z will, therefore, be equal to $100{,}800{,}000 + \frac{1}{3}y$. If there was no loss in accumulators, z would equal 100,800,000, and

$$z = \frac{100{,}800{,}000}{24} = 4{,}200{,}000 \text{ watts.}$$

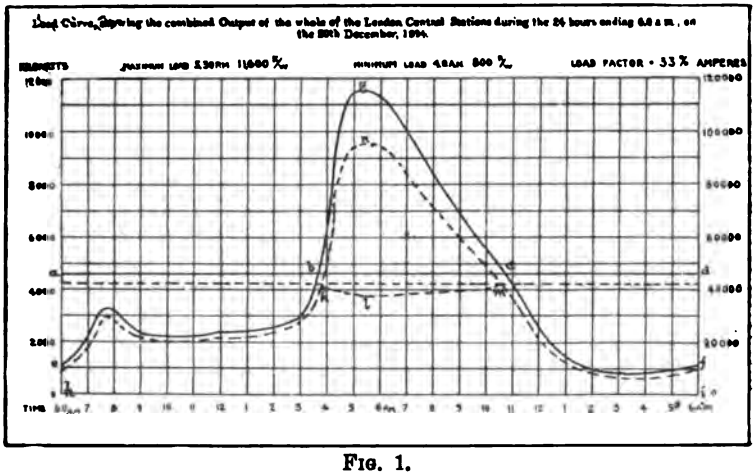

FIG. 1.

This value is plotted in Fig. 1 as a dotted line; this line cuts off the peak and would give the dynamo rating in watts, if there was no loss in the accumulators; by integration this amount is found to be 29,400,000 watt hours. This value inserted in the equation:

$$z = 100{,}800{,}000 + \tfrac{1}{3}y$$

gives

$$z = 100{,}800{,}000 + 9{,}800{,}000 = 110{,}600{,}000 \text{ watts per day,}$$

and

$$z = \frac{110{,}600{,}000}{24} = 4{,}608{,}333 \text{ watts.}$$

This value is plotted again in the diagram, and the new value for the area of the peak found as 28,800,000 watt hours. Inserting this value again in the equation, the value of z is found this time as:

$$z = 100{,}800{,}000 + \frac{28{,}800{,}000}{3} = 110{,}400{,}000 \text{ watts per day,}$$

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and

$$z = \frac{110,400,000}{24} = 4,600,000 \text{ watts.}$$

Now the value of 4,200,000 watts for z would render z for the dynamos too low, as no loss in accumulators was assumed, and $z = 4,608,333$ watts makes it too high, as the accumulator loss is taken in that case too high, the value of $z = 4,600,000$ is nearer to the correct value, and may be taken in the present case for the correct value, though it is possible to come closer to the correct value yet. Plotting a line corresponding to 4,600,000, which may be a, b, c, d, then the area e, b, c, f, i, h gives the watt hours delivered by the dynamos direct to the line; the area a, b, e plus c, d, f, the watt hours, charged into the accumulators.

The engine power required under the assumption of 90 per cent. efficiency of the dynamos would be:

$$\frac{4,600,000}{740} = 6,215 \text{ H. P.} + 10\% = 6,836.5,$$

or in round numbers 6,850 H. P.

It remains to determine the size of the accumulators. In the load diagram a dotted curve is sketched in, which is constructed on the assumption that the lamp voltage should be 110 volts with an allowable loss of 10 volts. The new curve represents the ampere load, the scale of amperes being at the right side.

The dynamos deliver all through the 24 hours 4,600,000 watts, therefore, at the time of greatest consumption, which is at 5:30,

$$\frac{4,600,000}{120} = 38,333 \text{ amperes}$$

will be the dynamo current, and the highest discharge current is obtained by subtracting these 38,333 amperes from the total current at this time: 96,666 — 38,333 = 58,333 amperes. The total current at 4 P. M. is 50,000 amperes, corresponding to a loss of

$$\frac{50,000 \times 10}{96,666} = 5.2 \text{ volts.}$$

Hence the dynamo current equals:

$$\frac{4,600,000}{115.2} = 39,930 \text{ amperes.}$$

At 10 P. M. the total current is again 50,000 amperes, and we obtain at this time the dynamo current also = 39,930 amperes. At 8 P. M. the total current is 70,000 amperes, as seen from the curve, corresponding to a loss of

$$\frac{70,000 \times 10}{96,666} = 7.23 \text{ volts.}$$

Hence,

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$$\text{The dynamo current} = \frac{4,600,000}{117.23} = 39,240 \text{ amperes.}$$

Plotting these values obtained for the dynamo current at the different hours into the diagram, the curve k, l, m, n, if integrated, will give the accumulator capacity = 240,000 ampere hours. From the price list of the Electric Storage Battery Company, a cell of 5,000 ampere hours capacity costs $375. If there is such a great quantity needed, the price of $375 would be reduced at least to $250.

$\frac{240,000}{5,000}$ = 48 cells in parallel would be required.

The potential of one cell is 1.85 volts, and as a maximum of 120 volts is required, $\frac{120}{1.85}$ = 65 cells as needed, hence the total number of cells = 65 × 48 = 3,120.

Price of cells = 3,120 × 250 = $780,000; interest may be fixed at five per cent., and depreciation at five per cent.

Then interest and depreciation on accumulators = $78,000.

For switchboards and meters a first cost of 10 per cent. on the accumulators would not be too low, the interest and depreciation on which may be taken at 10 per cent., then the annual expense for switchboard and meters equals $10,920.

The steam plant required was found as 6,850 H. P. Taking again the cost per H. P. at $64 + $\frac{1}{8}$ surplus power would give:

$$64\left(6,850 + \frac{6,850}{8}\right) = 7,310 \times 64 = \$467,840;$$

interest and depreciation at 10 per cent. would give $46,784.

The dynamo plant, figured at $25.90 per H. P., would amount to 6,850 × 25.90 = $177,420; 10 per cent. interest and depreciation gives annual expense for dynamos and switchboard as $17,742.

The amount of coal used per annum would be 6,850 × 24 × 365 × .16375 × $1\frac{1}{2}$ = 12,282,887 lbs., or 6,141 tons of 2,000 lbs. Then taking the cost per ton again at $2.25, the expense for fuel would be 6,141 × 2.25 = $13,820.

Cost of labor will be found as follows:

Three attendants at 25 cents per hour, expense per hour $.75; four firemen and one helper, at same rate per hour, $1.25; plus $1.50 for superintendence, which makes a total of $3.50 per hour, or 3.50 × 8,760 = $30,660 per year.

Cost of supplies and repairs equals 6,850 × 24 × 365 × .0008 × .16375 = 5,550 per year.

Adding all determined expenses, 78,000 + 10,920 + 46,784 + 17,742 + 13,820 + 30,660 + 5,550 = $203,476, against $241,960 found for regulation by shutting down part of the plant.

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MR. F. J. DOMMERQUE:—I would like to instance a few points which I have noted in Germany. I have had occasion to meet several engineers who had charge of large accumulator stations in Germany about three years ago, and asked them their saving in their special stations, and found it not less than 30 per cent. I think that further savings could be effected, as the accumulators could be placed in cellars, or in the third or fourth stories of buildings, and so the outlay for buildings would be decreased. In one city I found that the accumulators were placed two or three miles from the station itself. My experience has been that the first outlay was considerably higher than the entire steam plant, and it was feared the first time it would not pay at all, and that the city would have considerably money to pay in addition to the income. It was figured out, and it was shown, that where accumulators are used to any extent, that it was cheaper to use them than it was to use the battery engines.

MR. CARL K. MACFADDEN:—I have a set of accumulators about 180 in number, located at a large gas engine central station in this city, and although I cannot say the battery is taking a great deal of our evening load, I have every reason to believe that if we had the right size of storage battery auxiliary, we would get some excellent results. We have installed an electric light station of over 400 horse-power in gas engines here in the city, and have found in a number of cases that although the battery plant has a capacity of not over 600 ampere-hours, it has helped us in a wonderful way when we have had trouble with an engine, and we have found it especially valuable in very light loads, when it would not pay us to run the smallest engine, which is of 80 horse-power. I can see a very good chance of supplying storage batteries in certain stations, such as I have spoken of, and I notice that it is being taken up to an ever-increasing extent in European stations. With the improved methods of manufacturing storage battery plates, and with the guarantees which some of the larger manufacturers are now able to give, I see no reason why they should not be used to as correspondingly great an extent in America as in Europe. In small gas engine stations, there has been considerable attention paid to storage battery auxiliaries. In large gas engine stations, storage batteries will be used in conjunction with improved types of gas engines, so as to keep the engine up to its best load, for the gas engine ought to be loaded up to its rated load to get its best results, the same as the ordinary steam engine.

MR. LUDWIG GUTMANN:—The reason that the storage battery business is so well developed in Europe and almost neglected in America can, no doubt, be traced to the fact that in Europe until within the last year or two, with few exceptions, all installations were of the low tension continuous current type. In many places, especially in theaters, it was compulsory to provide means, such as storage batteries, to prevent a sudden giving out of light,

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due to defects in machines. On the other hand we find in America the majority of installations of the high tension alternating current order. I remember having seen stations some eight or nine years ago in England, for instance, that of the Alhambra Theater in London, in which the engine and dynamo capacity were selected smaller than necessary for the total output. The balance was installed in storage batteries, which were charged during the day and helped the two Edison dynamos at night to supply the light, while they were also used in the day time to supply the few lamps that were needed all over the house.

Here in America there was not such a great need for storage batteries, or, if it existed, it was not satisfied because capital was afraid of master patents such as Brush, Faure and Planté, and, no doubt, a pressure was exercised by the companies controlling these patents on others who wanted to venture into the storage battery business.

However, now the fundamental patents having expired, we will experience a greater activity in the development and manufacture of storage cells. The need for such cells has been growing steadily, and I believe that no great stimulation is required for their introduction.

In Europe circumstances aided the development of this branch, and among these were the prohibition of overhead wires in many cities, and the use of too great engines, which would have needed considerable valuable space, heavy foundations, also large space for receiving and storing coal. The battery was a means of permitting the use of a smaller engine and dynamo and storage of the energy, preparatory to the heavy demand.

It seems to be an American trait to neglect one undeveloped branch of the business at the expense of another which is advanced to the greatest extent. I wish to remind you of the sudden start of many engineering firms into the high tension alternating current work in 1887 and 1888; then the vigorous attack on the railway motor and its development, and now since that has also passed into a field of stability, there is a unanimous attack prepared to solve the storage battery problem. The fruit is worth looking for, as the usefulness of the storage battery is far greater than may be thought for at first sight by many. It will not be restricted to low tension continuous current work, but it will be used in central station distribution by means of high tension single and pluri-phased alternating currents which are changed by rotary transformer into continuous currents to charge the batteries with the surplus energy the dynamos develop at the time of light loads.

Mr. Sheehy:—With reference to my experience with storage batteries in connection with signal work, I will say that it is of very recent date, and, in fact, I might say that the various classes of batteries have been used. I had to do with the first one used

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in this country, as well as those brought from Europe. I do not think there is anything I can say to add to the discussion this evening. So far as my faith in storage batteries is concerned, I believe very emphatically in its use, and would even go further in my endorsement than any one here to-night has gone.

Mr. M. H. Gerry, Jr.:—I am much interested in the application of storage batteries, and have listened with great pleasure to the remarks I have heard this evening. I am profoundly impressed with the desirability of using storage batteries in connection with fluctuating loads for both lighting and power purposes, provided that batteries can be found which will satisfy commercial conditions. Much has been written in the past in regard to the great losses and rapid deterioration of storage batteries, but I cannot help thinking that the results may have been partially due to improper handling, or inefficient apparatus for regulating the charging or discharging currents. If a storage battery can be obtained, costing not more than the same kilowatt capacity of a first-class prime mover, having a commercial efficiency of 75 per cent., and a cost of maintenance not greater than six per cent. of the investment, then such a battery can be used in a great many power stations with advantage in point of economy. It is only a question now, whether such a battery can be obtained, and a great many practical engineers are looking with considerable interest in the direction of storage battery manufacturers.

I have listened with pleasure to the gentlemen here to-night who have had large experience in this attractive field, but regret that they have not said more in regard to deterioration, and to the maximum discharge which batteries can safely stand. I would like to add a word in reference to the rating. The present method of stating the capacity in kilowatt-hours or ampere-hours is not altogether satisfactory. More important than the total capacity in the application to fluctuating loads is the maximum rate at which a battery can be repeatedly discharged without seriously damaging it. A kilowatt rating representing this maximum discharge would be of more value in cases of this kind than the kilowatt-hour or ampere-hour rating above referred to.

Mr. B. J. Arnold:—The first thing which I wish to call attention to is the discussion of Mr. Perry, in which he advocates the use of gas engines for taking the peak of the load, or the fluctuating load of electric plants, instead of batteries. He states that under no circumstances would he recommend the use of batteries, for the simple reason that the gas engine will be found more economical. I think this is rather a broad statement, and one which the advocates of this system will have some difficulty in substantiating, for the reason that gas engines working on variable loads are extremely uneconomical, and not only are they uneconomical, but they are very sensitive to changes of load. If the load on a gas engine changes suddenly, it is liable to re-

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quire immediate attention on the part of the operator to keep it in operation, as indicated by my experience with some engines. It is probable that certain makes of engines are more reliable in this particular than others, but under any circumstances it is almost imperative to have an attendant near a gas engine while it is in operation, if working on variable loads. For this reason and the fact that the gas engine is uneconomical at light loads, the plan of placing gas engines in different localities over which a system of electrical distributing mains were being operated, in order to help out the heavy loads at distant points would be impracticable, as each engine would necessitate an attendant to start the engine at the time that the line required extra power. On a railroad circuit, this demand is constantly changing from the negative to the positive factor, and if a gas engine is used, it would be running a portion of the time with practically no load, and the next instant with excessive overload. A battery installed in the same locality would receive the excessive current delivered to it when the demand on the line was light, and discharge it into the line when the demand was heavy, automatically, thus storing the energy and giving it back when needed, without the services of an attendant. The figures given by Mr. Perry, showing the consumption of gas at various loads, show that the engine consumes over three times as much gas per H. P. when running at one H. P. as it does at 12 H. P., its rated capacity, and in railroad work the engine would be thus running a large portion of its time, and I believe that the results would be far from satisfactory to the company operating such a system, especially if there were any number of engines in operation. A gas engine could be installed as an auxiliary to a central station to carry the peak of the load if it was comparatively steady, as is the case in lighting plants, but my judgment is that it will be much better economy and engineering to put in another steam engine, which could be driven from the same battery of boilers, steam piping, etc., already in the station, than to install a gas engine and necessitate the attendance of engineers especially skilled in handling both steam and gas engines. There is no question in my judgment but that a gas engine plant, installed properly and run on producer gas, will deliver a K. W. hour on the switchboard for less money than a steam engine plant can do it, but in order to do so, the engines must be run at practically a constant load. Such a plant, working in conjunction with a battery auxiliary, I believe to be the most feasible solution of the power station question, and one which we will probably come to in this country in the near future.

Probably of more interest than any general discussion of this question will be some specific cases showing the application of batteries. I have brought with me to-night some load diagrams of stations in which batteries will be installed. The first, shown in Fig. 2, represents the diagram of a railroad plant operating

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near Chicago. You will notice the similarity of the peaks, and that they occur at equal intervals of time. This is caused by the road having upon it a four per cent. grade, about one-quarter of a mile long, up which a car is propelled every 20 minutes, there being four cars in operation on the line, and so spaced that the cars reach this grade 20 minutes apart. The result is, that it was necessary to install a very much larger engine and generator in this station, in order to take the maximum load of the line when the car reaches this grade, necessitating the operation of a 250 H. P. engine the entire 18 hours that the road is in operation, merely to be able to haul one car up this grade, and to operate the other three at the same time. This was the first case that occured in my experience wherein I thought it advisable to recommend the adoption of a battery auxiliary. After making an accurate test of the plant, I found that the total average energy required from the power station to operate the road was about 50 electrical H. P.; consequently, if an engine and generator of 65 H. P. were installed and working in conjunction with a battery auxiliary, the road could be operated with this size plant, and the large engine shut down. I am unable to give you the results of this installation, as it is not yet running, but hope to at some future time. You will readily see that an investment for a 65 H. P. engine and generator and a battery auxiliary, to do this work, is much less than is at present carried to do the same work.

The most important application of batteries to lighting work, which I have had to do with, is the plant now being installed in the Chicago Board of Trade. In this plant the operating expenses average now about $25,000 per year, using simple engines at 75 lbs. of steam, hydraulic elevators with compound pumps working steam full stroke, and old style belted electric plant with shafting. By increasing the steam pressure to 125 lbs., installing new boilers, new compound engines, and with direct connected generators, electric elevators and a battery auxiliary, we expect to reduce the operating expenses to $15,000 a year. The present system of operation necessitates the use of three shifts of men, working eight hours each, making the labor pay-roll rather high. With the new system, using the battery auxiliary, there will be but two shifts of men, working eight hours each; a third man working but eight hours, thus reducing the cost of labor in the plant very materially, as the battery takes care of the entire load for a period of eight hours. At present it is necessary to signal to the engineer to start up the engines and dynamos when the janitors require light at night, while sweeping the rooms, and to use the hydraulic elevator. With the new system, the battery will handle the elevator and lights in the building automatically at night.

Referring to Fig. 3, which represents the load diagram of the plant of the Chicago Board of Trade as it now is, and as it will

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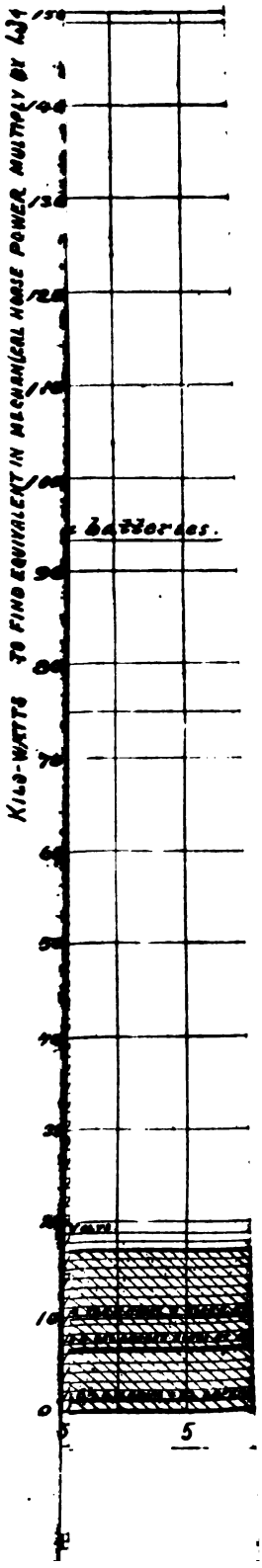

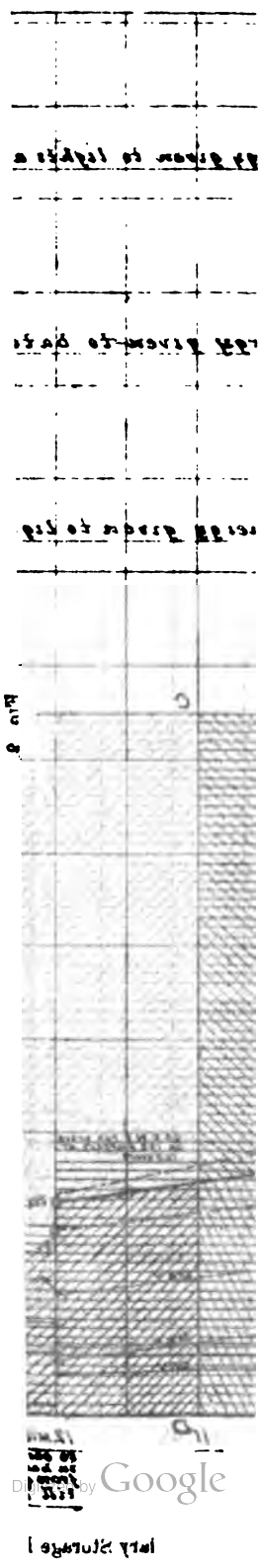

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Fig. 1

be when the revised plant is in operation; the lower lines of the diagram, representing the various lighting loads, and the large line *A*, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *j*, *k*, *l*, *m*, *n*, *o*, *p*, *q*, representing the load of the plant for 24 hours under the new conditions. The parallelogram *A*, *B*, *C*, *D* represents the total electrical energy of the 75 K. W. generator, operating from 7 o'clock A. M. until 11 o'clock P. M., over a period of 16 hours, involving two shifts of labor at eight hours each. That portion of the parallelogram, having shade lines inclining to the right at an angle of 45 degrees, represents the energy which will be delivered from the generator to the batteries. That portion of the diagram having shade lines inclining to the right, at an angle of 120 degrees with the base line, represents the energy which will be delivered to the line direct from the generator without the aid of the batteries, while that portion represented by the shade lines inclining to the left, at an angle of 45 degrees, represents the energy given to the line from the battery alone. It will be noticed that between the hours of 9 A. M. and 2 P. M. the batteries act in conjunction with the generator, as the demand is in excess of the capacity of the generator, while from 11 o'clock P. M. until 7 A. M. the entire load of the plant is carried by the batteries without the aid of the generators, thus leaving all of the plant, except the batteries, idle for this period of the twenty-four hours, and necessitating but one attendant during this time, who fires the boilers in the winter for steam heating, and also acts as watchman. With this arrangement, the 75 kilowatt unit operates for a period of sixteen hours at its maximum economical load, and is then shut down and stands idle until the next operating period. From this plant will be operated 1,000 16 C. P. incandescent lamps, four 10 H. P. electric motors, four 30 H. P. electric elevators, and it is expected that one 75 K. W. generator will handle this load economically when the plant is completed, it being understood that the maximum capacity of these machines is seldom required at any one time. With this arrangement, lights or power can be turned on any part of the building at any time during the entire 24 hours of the day without necessitating any attention from the engineer in charge, thus gaining not only economy, but a great feeling of relief on the part of the operators, which they do not now have, or for that matter do not have in any plant operating on a variable load without the use of some kind of a reservoir, in the shape of a large engine, running underloaded, or a battery auxiliary.

Mr. Abbott has given us a very carefully prepared discussion upon the cost of the operation of the London lighting plants, when operating as they do now, and has shown what might be expected, if they were operated with battery auxiliary.

The records of European stations, so far as I am able to secure, show that the plants operating with battery auxiliary are delivering a K. W. hour to the consumer at a somewhat lower rate than

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those operating without batteries, when the conditions are similar.

The chief difficulties which have prevented the introduction of batteries on a large scale in this country in the past have been as follows:

1. The danger of suits for infringement wich were liable to follow in case a purchaser attempted to use batteries.

2. The desire on the part of the manufacturer to furnish a battery for as low a cost as possible, and in many cases installing them of too small size to do the work required, the result being rapid deterioration and subsequent disastrous results to the battery business.

3. The lack of knowledge on the part of the operators or attendants in charge of the batteries.

A battery plant properly built, with sufficient lead to do the work required of it, and properly handled, will prove an economical investment where the conditions are favorable; but it should be borne in mind that a battery, like every other power-saving device, cannot effect a saving, unless the load is such as to warrant its use, which is especially the case on variable electric loads.

Those having charge of plants using batteries should bear in mind that batteries absorb and give out energy by virtue of a chemical action, and that anything which in any way prevents the proper harmonizing of the chemical elements entering into the batteries, begins to cause deterioration immediately. Consequently early attention must be given to defects, or serious results will follow. In other words, a battery plant is like any piece of mechanism or other device which requires some knowledge on the part of the operator to keep it in good condition, and as before stated, a large part of the battery failures in this country have been caused by the attendants not thoroughly understanding the device they were attempting to handle, and thus allowing destructive chemical action to continue until the batteries were practically destroyed, when attention at the right time would have prevented it.

The system which I have adopted for all plants installed under my direction is as follows:—*First*, I insist upon a recording ammeter being placed upon each plant, and daily charts from each plant mailed to my office. In this manner I am able to tell immediately whether or not the cells of any particular plant are being overcharged, overdischarged, or gradually discharged more than they are charged, until the surplus of the cells is exhausted, which is one of the chief sources of disaster in batteries. *Second*, each week the plant is examined by an expert, and the specific gravity of the electrolyte of each cell and the voltage of each cell examined and placed upon a report and handed in. From this we are able to tell whether or not the cell is short-circuited, or the electrolyte too heavy or too light for economical working, and

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if defects are noted, the operator of the plant is notified immediately to remedy the defect, and if he is not capable of doing this, an expert is sent to do it. By this system of inspection it is hoped that a sufficient number of plant operators will become skilled enough to properly handle a battery installation, and after that time, I think, we will have fewer storage battery failures.

MR. MACFADDEN:—I would like to ask Mr. Arnold whether or not those tests on steam engines and on gas engines, were made on brake tests or indicated horse-power. I have found that in some gas engine plants with which I have had to do, that the gas used per indicated horse-power varied but little with different loads. It will be found that the gas used per indicated horse-power will run very nearly the same whether the engine is running under load or over load; also, that on some tests of a 200 H. P. engine, when on half load and under, we can get practically the same results for indicated horse-power, where consumption of gas is concerned, as we can for full loads. Also that the highest efficiency for this particular engine is not at the point of maximum possible load. I mean that the highest efficiency of that engine is not reached when the engine is doing its maximum work. I can take an engine that is designed to run 55 brake horse-power, load it up to 70 brake horse-power, and the engine will carry it. The highest efficiency is not obtained with the highest possible initial pressure that can be obtained. I think that this is somewhat different from the usually accepted views with regard to the gas engine, and I have the data which I will distribute to those who wish to investigate the matter. It would be especially interesting in this case, provided the tests were taken as indicated horse-power instead of brake horse-power. The amount of gas and fuel for indicated horse-power, I think, will be found to be somewhat different from brake horse-power. Mr. Perry gives the data of a test on horse-power development. I should imagine that this means in the cylinder, in the absence of anything stated to the contrary, the gas consumption being too low for brake horse-power.

MR. ARNOLD:—I would say that I have examined the engines you have referred to, and find them to be double cylinder engines which explode once at each cylinder, or twice at each complete revolution of the shaft, and it is undoubtedly true that such an engine can stand a heavy overload better than many types of gas engines.

PROF. CARHART:—I regret that I cannot give you any information on the commercial side, but I have been very much interested listening to the discussion here this evening. I have had a little experience, however, with storage batteries. Three years ago I had the pleasure of visiting, in company with several other gentlemen, the central stations of London, through the kindness of Professor Silvanus Thompson. We visited all, or nearly all, of them, and, as you know, the storage battery is an important

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factor in all these stations. One thing that impressed me very much, in comparison with what I had been accustomed to see in connection with storage batteries in America, was the fact that they construct their storage batteries there for durability. The cells were of enormous size and capacity. They were extremely heavy, and intended for actual use. They were not made, apparently by the manufacturers, to make money out of, by selling cheap metal at a high price, but they were made for service and durability. In connection with that, it occurred to me that there must be quite an addition to the cost of the plant besides that of the battery installation, namely, provision for its storage. The building costs as much where the storage battery is used, as it does where it is not used, because of the very large area required for the placing of the batteries. There are a good many appliances, too, as you know, in connection with a storage battery plant in addition to the cells themselves. The arrangements for throwing cells in and out, according to the requirements of the plant, are very elaborate and costly. They are put up in an attractive and substantial manner. They are not placed in cellars, nor yet in attics, but in very substantial buildings. They are running their engines there at the point of highest efficiency, because the number of engines changes with the load. As the load comes on, additional engines are started up. And yet they find it economical to use the storage battery in connection with their plants.

Another item ought to go into Mr. Abbott's estimate, and that is, the cost of the acid required to set up the cells. The cost of acid amounts to considerable, for the acid ought to be of the purest quality. I have had a little experience with two types of battery. I think the Pollak battery is a thoroughly good one, but it certainly depreciates quite rapidly. In the one that I have, some of the cells have had to be taken out and repaired. The people in charge of these stations in London, which use storage batteries, watch them very carefully, and when anything is the matter with them, they put them in the hospital. Storage cells remind me of an invalid, requiring great care and watchfulness. They must be taken care of and watched, when they are not giving their highest efficiency. They require considerable labor, and this item ought to be added to the account. It requires the labor of one or two experts continually, to look after these cells. I think the last battery that I have tried, gave out toward the close of last year from the fact that it stood a long time without being used. I inquired of Mr. Pollak regarding this, and he assured me that it could be left standing. Mine, consisting of 36 cells, did stand without losing more than two volts in three months. The voltage scarcely dropped at all. I measured carefully to assure myself that it kept its voltage during that period. But there was sulphating under the active material, and when we came to use it, it would swell in spots. Mr.

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Pollak insisted upon it that some foreign material must have gotten into the cells which caused them to give out. But I think it came from the fact that the cells were not kept in constant use. I found that it don't do to let them stand. It is like the human body in this respect, the cell needs exercise to keep it in good condition.

I have come across one or two points of scientific interest. It is certain that the internal resistance of a storage battery changes considerably with the length of time that it is discharged. As it is discharged, we have a sulphate formed, which has a higher resistance than the active material. This internal resistance will change in the course of charging for half-an-hour. Then there is another point. You all know that the internal resistance of any primary battery decreases as the current increases. We have been able to get very nice smooth curves. With a storage cell the change is small and is quite difficult to measure, but measurement shows that the internal resistance is lower when the current which we are taking from the battery is larger.

Mr. Arnold:—When you start charging a battery, you can force current into it for a while with a lower voltage than you can when the battery becomes partially charged. Is not part of this attributable to the lower internal resistance of the battery when not fully charged? As the cells become charged, it is necessary to increase the voltage of the charging current in order to keep the charging current constant. This must be due to the increased internal resistance of the battery. It is well known that the resistance of a mixture of sulphuric acid and water is least, having a specific gravity of about 1.123 at ordinary temperatures, and, as the specific gravity varies either way from this, the resistance increases.

Prof. Carhart:—The internal resistance falls as you charge, because the sulphate is reduced, and for that reason it ought to take less voltage to force the current through. The battery does not have as high efficiency when it is discharged with a large current as when it is discharged with a smaller current, but the smaller internal resistance is a slight offset.

Mr. Dommerque:—I remember that the company which manufactured the accumulators for Hanover, Germany, has made a contract with the city to keep them in perfect running order at four per cent. of the first cost for ten years, and that this company makes money at that, which I conclude from the fact that when I was there in 1887, they ran their factory by a small locomobile, while to-day they have immense factories at Hagen, Berlin and Vienna. In most stations the accumulators have a space about one-half to one metre square for each cell. On the Continent I found that they do not give accumulators a very good place, but put them in basements, or somewhere where the ground does not cost so much. I think this is cheaper than to provide space for engines or dynamos instead, because the latter must have a good foundation.

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PROF. W. M. STINE:—It seems singularly appropriate to enter a plea for the proper consideration of the storage battery itself in connection with its engineering applicability for lighting and power uses. It is 35 years since Gaston Planté (1860) made the first experiments from which the storage batteries of the present have been developed. The field has been a prolific one for investigation and invention The storage battery is thus older than dynamo-electric machinery by about seven years. Sufficient time has certainly elapsed for the practical development of this class of apparatus. Yet after 35 years we are still telling each other how excellent a thing the storage battery would prove, were it only more generally used, and still in the dark for reliable data on which to base our conclusions.

There is good reason for the lack of data for the life and usefulness of storage batteries. Through all the years they have been with us, they have existed in tentative form, and their history is a failure of one form, leading to fresh experiments on others. That they have recently been the subject of large speculation by some of our leading financiers is by no means a convincing argument in their favor. This is neither the first nor the greatest financial combination of its kind, and should it not prove successful, it is only adding one more to a long list of disastrous failures.

The engineering view of our subject has been frequently and pretty exhaustively presented, but too often by those who have had no practical experience with batteries, and whose estimates of first cost, maintenance and depreciation are far below the actual figures.

A commercially practical storage battery would be one of the greatest boons to electrical engineers. This is undeniable. It does not require any especial foresight to realize the great advantages accruing from their use. The problem of when and how far to employ them, is not more difficult of solution than the most advantageous amounts and distribution of copper in distributing circuits. It requires that a sufficient number of load curves be taken to get a reliable average curve. It then remains to determine the size of generating plant to handle the average load, and the addition to this to handle the peaks in the load, allowing sufficient reserve to handle the maximum peak likely to occur. The equivalent in batteries of this reserve portion of the plant can then be calculated. The total operating expense in each case would present no especial difficulty, were data at hand, which would reliably state the depreciation, maintenance and labor involved by the use of storage batteries. Additional elements would be the enhanced efficiency of the generating plant when run with a nearly constant load of the service and battery combined, and the power factor of the batteries, or their efficiency from the generator to the consumer. With such data as outlined, the question of the commercial applicability of the

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storage battery would be a very simple one. All that would be necessary would be to balance accounts between the two classes of reserve plants. On the one side would be the first cost of generators, engines, boilers and accessories, labor, maintenance, operating expenses and depreciation. On the other, the first cost of the reserve equivalent in batteries, their maintenance, depreciation, operating expenses, labor, and the large number of accessories. Here conscientious calculation would leave but little room for discussion, except on methods and details of installation. If the problem has been fairly stated, then why does the present hesitation to install batteries exist? There is no doubt that storage batteries would prove desirable adjuncts to many power and lighting stations, and would be generally introduced, could any reliance be placed upon such low depreciation as 7½ per cent., as has been recently stated.

But American engineers are justly conservative on this latter point. In too many cases the depreciation has reached 100 per cent., or the batteries have been abandoned in a short time.

It is undeniable that a strong sentiment exists in this country against the storage battery. Most of the data obtainable is against it. Under such circumstances it would be wise to make haste slowly, and let the burden of the introduction of batteries rest on the company manufacturing them.

The argument that the engineering world wants, is not engineering calculations showing a paper economy, but it wants to be granted the demonstration of plates that have stood at least from 1,500 to 2,000 daily reversals on continuous service. A battery of which at least 90 per cent. of its plates could make such a showing would be not a mere curiosity, but a most convincing argument.

The general trend of practice is to employ a greater weight of lead per ampere-hour capacity. Those who have had much experience with storage batteries know that plates fail from at least three causes: (*a*) the loss of active and irreversible material falling to the bottom of the cell; (*b*) rupture of plates due to mechanical strains; (*c*) disintegration, or crumbling of the supporting structure of plates.

Heavier plates, then, will remedy the second and third faults to a limited extent, but be without influence on the first. The heavier plates suffer the same actual loss in pound weight of active material as lighter ones, but can support the loss for a greater length of time. But the proportionate life of a heavy plate, owing to physical disintegration, may in reality be less than the lighter one. The interest on the first cost of the extra lead which is used to ward off the day of final destruction, is a direct loss, unless the proportionate life of the heavy plate greatly exceeds that of the lighter one. The use of more lead in plates, by no means diminishes the wear on batteries.

It has been so often proven that the use of reliable storage

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batteries is excellent engineering practice, that the arguments have become mere platitudes. But where shall we obtain the reliable battery? Certainly it is yet to be proven that it is made in America. Can we point to any make of battery that has stood up under at last five years of ordinary commercial service? The records of the Patent Office show that the storage battery has received its full share of attention from inventors, and yet we hear the common report from the different styles of plates that they have gone to pieces under short service. Litigation is claimed to be responsible for the non-use of storage batteries in this country. Yet we all know better than this. If a perfectly reliable battery had existed, it would have come to the surface in spite of all lawsuits. The very fact that manufacturers are constantly changing the form of plates, etc., is sufficient argument to show that plates will not stand up under service. Great stress is laid on the extensive use of the storage battery in England, Germany and Switzerland. But here the plants are too modern to prove their ultimate economy. One of the oldest and best known of English plates is rumored to be proving a failure, for the very reason that this plate has been in use long enough to demonstrate that it does not possess sufficient life.

European practice offers a counter argument. The fact that batteries are used there so extensively, shows that they must prove at least a partial success. Let American engineers, then, profit by European experience. Let us go to them for our information. But how shall this be obtained? The suggestion is offered that our technical papers procure from European central stations using storage batteries reliable statements which shall, without fear or favor, state fully all facts in regard to their installation. Such data should note the style of battery in use, its ampere-hour weight, the purity and specific gravity of the electrolyte, the methods pursued in operating and caring for batteries, first cost of batteries and accessories, their actual power factor, the outlay for repairs and renewals, the length of time the battery has been in actual service, and the life of plates so far as used.

Another question remains to be decided. Can batteries be profitably sold outright? In very many cases the manufacturer has maintained a fostering care over plates installed, and the life shown has in a measure been due to frequent patching up of plates.

Among points not sufficiently emphasized by many writers, is the great outlay for the numerous expensive accessories demanded by a first-class installation; the constant attention and treating which they demand, and the disagreeable nature of repairs due to handling sulphuric acid.

A notable article appears in the *Elektrotechnische Zeitschrift* for October 17, 1895. It fully states just such data as we desire, for an installation of 120 cells of Tudor battery made in Hagen, Westphalia. The cells were 52 ampere-hours capacity; normal

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discharge rate of 10 amperes, and charging current of eight amperes. The battery was installed in 1890, and has been in constant use. With the exception of renewal of electrolyte in one cell, no repairs or renewals were necessary. The installation was for the Head Bureau of Telegraphs in Berlin, and used on its service wires. The discharging current never exceeded 0.25 amperes. The cells were charged each 10th—11th day. On analysis of the record, owing to the small discharge current, we can draw no conclusions as to what would have been the life of the plates under conditions of normal discharge, say 5 to 10 amperes. These batteries in all have been reversed not to exceed 200 times, this being equivalent to not more than one year's active service, such as would have been required of them in lighting and power plants. An increase in capacity is noted, a condition which is to be expected under such service.

It is to be hoped that this timely article will be followed by many others equally reliable.

Mr. Arnold:—In referring to the maintenance, it seems to me that the best evidence that could be relied upon is the guarantees which are made by the companies that are backing these battery installations with their money. They are not going to guarantee something which they do not believe they can depend upon, and I do not see any reason for doubting their ability to do this, when they are willing to make contracts which make them liable if they are not able to fulfil their promises. I believe batteries can be maintained at a profit for seven and one-half per cent. of their first cost per annum when working within their limits.

Up to the present I have not been in favor of batteries being put upon street cars, but figures which have recently been shown me from the records of a road operating 25 cars in Paris, in which the maintenance of batteries is given at $\frac{63}{100}$ of a cent. per car mile, covering a period of over two years of operation, causes me to look upon this question more favorably, and if on investigation this record proves to be correct, many of us may have to change our minds regarding storage battery cars. One thing is certain, that the first cost of a road is less with storage battery equipment than it is with trolley equipment, for the reason that the power station investment is less, and there is no expense for the overhead or feeder system. A set of cells in this city which have been used over two years now, none of which has been returned to the factory for repairs, are reported to me to be in as good condition as they were the day they were started. These are operated on a fluctuating load, but evidently have not been overworked. I attribute a large portion of the durability of this particular plant to the excellent quality of lead used in the construction of the cells. This, together with the use of chemically pure acid, and the careful attention which has been given by the operator who is an expert on battery work, has shown an excellent result, confirming more than ever my belief that the thing

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we need most in this country at present is a class of trained men, capable of handling batteries properly, rather than radical improvements in the batteries themselves.

Mr. Feldman:—In the *Electrician* (August 30) are given the latest results of using storage batteries by the Birmingham, England, Central Tramway Company to work the cars. The figures presented by the chairman of the company showed that while the mileage had remained stationary, the receipts had decreased six per cent., and the expenses increased 27 per cent., the total cost per car mile having grown from 14¾d. to nearly 18½d. The exact figures of the four different systems supplied by the company per car mile are as follows: Cable, 5.43d.; horse, 8.67d.; steam, 9.11d.; storage batteries, 18.43d.; while last year a profit of over £1,200 had been earned by the accumulator cars. This year the chairman reported a loss of £1,735.

Mr. Dommerque:—I had the good fortune to meet Mr. Tudor in 1887, and he himself told me that he had had accumulators in service for seven years, which he charged regularly. He says, that figuring on this basis, he could guarantee for 10 years, and that the repair bill would not amount to more than 10 per cent. of the first cost.

[Adjourned.]

Discussion in San Francisco.

A meeting of the California members to discuss the topic of "Storage Battery Applications" was an after-dinner feature, at Frank's rotisserie in San Francisco, on the evening of November 30th, Vice-President W. F. C. Hasson, in the Chair. Mr. E. J. Molera opened the discussion giving a review of the early history of the storage battery, and an interesting account of his own experiments. He also exhibited the first Planté cell imported into the country.

Dr. F. A. C. Perrine, Local Secretary, then read extracts from the communications presented by Mr. Childs and others at the New York meeting, after which he gave the following contribution to the discussion:

"The importance of the auxiliary use of storage batteries in comparatively small plants operating electric lights and electric railroad systems has not been widely discussed, although the principles involved have been indicated in all papers by the advocates of the batteries. In order to make a comparison of an auxiliary storage battery for a small electric light plant and a similar electric railroad plant, I have obtained the enclosed load curves derived respectively from the San Jose, Cal., street railroad and electric light systems. The curve of the lighting plant (Fig. 4), while showing a great variation between the maximum and minimum load, indicates at the same time that there is no well defined peak in the lighting curve of such a system, and

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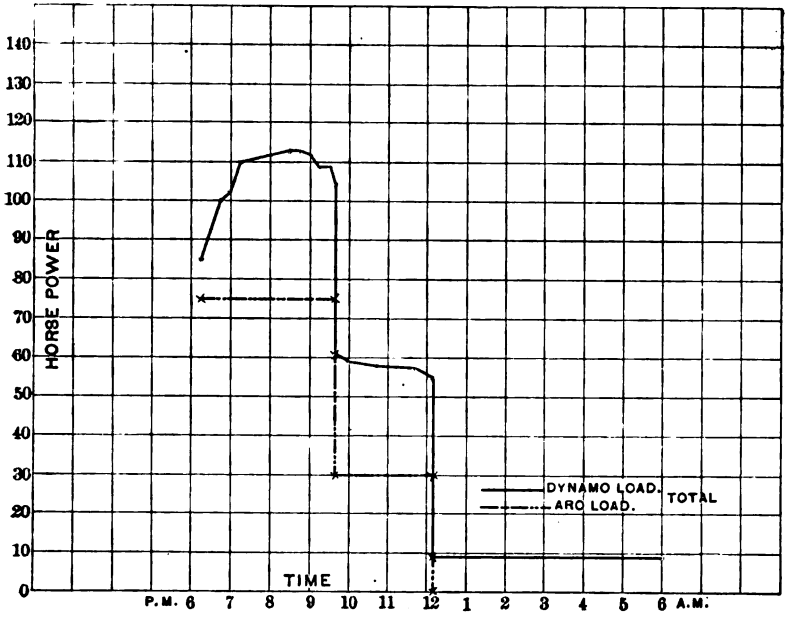

FIG. 4.—Load Curves, San Jose (Cal.) Light and Power Co.

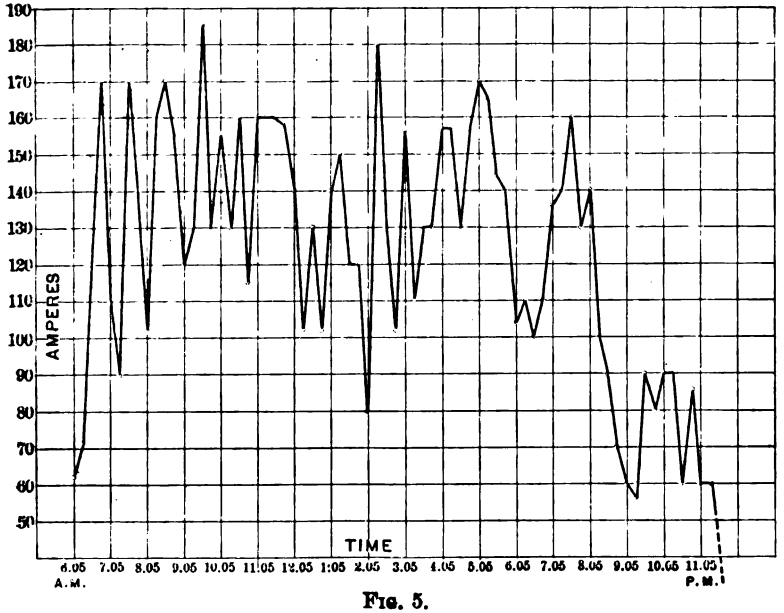

FIG. 5.

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particularly on account of the relatively small importance of incandescent lighting in residences when compared with the incandescent and arc lights sold by contract, we see that the only value an auxiliary battery plant would have in any such station lies

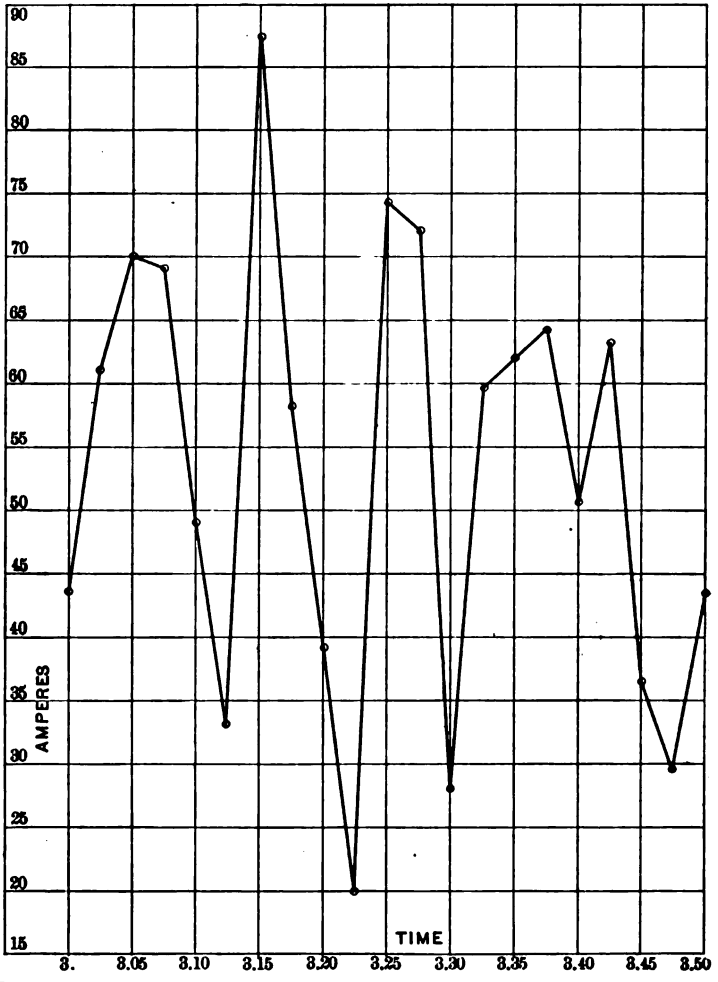

FIG. 6.—First Street car curve. Five cars. Showing changes in current along one line as the five cars are operating in the time of one trip. The drop along this line varies with the current curve.

in its ability to carry the load between the period of extinguishing the city lights at night, and the time they are again turned on the following evening. In the particular plant under consideration, a test has shown that the amount of coke used per

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indicated horse-power hour during the main period of illumination (from 6 P. M. to 12 P. M.) is 10.8 pounds, in spite of the incidental variations and the low peak; while if we turn to the electric railroad curve (Fig. 5), we see not only an average peak, which is as clearly defined as that belonging to the lighting plant, but also that a variable loss occurs along the line. This loss amounts in the present case to a maximum of 15 per cent. Under such circumstances not only would the generating machinery be operated at a better maximum efficiency were storage batteries installed, but also by locating them along the line and not simply at the generating station, the great loss we speak of would be overcome without the use of additional feeders, and the cars could be run on a better time schedule and with greater satisfaction to the traveling public. At the present time the cost of the storage battery and its probable short life hinders extensive introduction into such plants. The average price at which storage batteries are furnished at the present time amounts to as much as 75 cents per pound of grid, which certainly seems excessive for such apparatus; and, while noting this high price, there seems to be no reason why battery makers should not increase the weight of lead in the battery grid, especially when we consider the fact that in such an increase of weight lies the secret of low maintenance cost for storage batteries. German manufacturers have realized the importance of this increase of weight and its small addition to the manufacturing cost, on account of the fact that they are required to guarantee the life of the cells, and it is to be hoped that the recent introduction of European batteries into this country will have a tendency toward heavy battery plates, with a consequent increase in life, and diminution of troubles due to buckling and short-circuiting. When these difficulties are completely overcome, as is now easily possible, the great first cost of the batteries will undoubtedly not militate so largely against their installation as it does at the present time."

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

ASSOCIATE MEMBERS ELECTED BY COUNCIL.

New York, Dec. 18th, 1895.

Name.	Address.	Endorsed by.
BANCROFT, CHAS. F.	Electrical Engineer, Lowell and Suburban Street Railway; residence, 60 Fort Hill Ave., Lowell, Mass.	C. P. Steinmetz. Wm. G Ely, Jr. Ernst Berg.
HERDMAN, FRANK E.	Mechanical and Electrical Engineer, Crane Elevator Co., Winnetka, Ill.	A. V. Abbott. B. J. Arnold. W. M. Stine.
LAMB, RICHARD.	Chief Engineer, The Trenton Iron Co., No. 1 Broadway; residence, 72 West 69th St., New York City.	T. C. Martin. Jos. Wetzler. N. Tesla.
LE PONTOIS, LEON.	Electrical Engineer, The Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	Chas. F. Scott. Henry Floy. Alex. J. Wurts.
LUDLAM, HARRY W.	With Western Electric Co.; residence, 480 Lexington Ave., New York City.	Geo. A. Hamilton. M. E. Canfield. H. F. Albright.
MCMEEN, SAMUEL G.	Assistant Engineer, Central Union Telephone Co., 1306 Ashland Block, Chicago.	A. V. Abbott. A. S. Hibbard. B. F. Thomas.
SCIDMORE, FRANK L.	With Western Electric Co.; residence, 480 Lexington Ave., New York City.	G. A. Hamilton. M. E. Canfield. H. F. Albright.
STONE, JOSEPH P.	Electrical Engineer, General Electric Co.; residence, 213 Liberty Street, Schenectady, N. Y.	C. P. Steinmetz. H. G. Reist, Wm. G. Ely, Jr.
STORER, NORMAN W.	Electrical Engineer, Westinghouse Electrical and Mfg. Co., Pittsburg; residence, Wilkinsburg, Pa.	Chas. F. Scott. Alex. J. Wurts. Henry Floy.
THORDARSSON, CHESTER H.	Chicago Edison Co; residence, 896 Davis St., Chicago, Ill.	Chas. A. Pratt. B. J. Arnold. W. M. Stine.
WYBRO, HARRISON C.	Electrical Engineer, Wybro & Lawrence, Los Angeles, Cal.	T. C. Martin. F. A. C. Perrine. Leo Daft.

Total, 11.

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Approved by Board of Examiners, Oct. 11th, 1895.

STEPHENS, GEORGE,	General Superintendent, Canadian General Electric Co., Peterboro, Ont.
WHITE-FRASER, GEORGE,	Electrical Engineer, Toronto, Ont.
DOW, ALEX	Engineer, Public Lighting Commission, Detroit, Mich
NEILER, SAMUEL G.	Assistant Electrical Engineer, Pierce and Richardson, Chicago, Ill.

Approved by Board of Examiners, Nov. 6th, 1895.

PEROT, L. KNOWLES	Vice-President and General Manager, Schuylkill Valley Illuminating Co., Phœnixville, Pa.
BLOOD, JOHN BALCH	Assistant Engineer, Railway Department, General Electric Co., Schenectady, N. Y.
SHEBLE, FRANKLIN	Electrical Engineer, Philadelphia, Pa.
FREEDMAN, WILLIAM H.	Tutor in Electrical Engineering, School of Mines, Columbia College, New York City.
RIKER, ANDREW L.	The Riker Electric Motor Co., Brooklyn, N. Y.
McCROSSAN, JOHN A.	Manager and Electrician, Citizens' Telephone and Electric Co., Rat Portage, Ont.

Total, 10.

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OBITUARY.

George May Phelps, [*Associate Member, April* 15, 1884, *Member, October* 21, 1884,] who faithfully served the Institute as Treasurer from his first election to that important office, on May 17, 1887, died of pneumonia at his residence in Brooklyn, N. Y., on April 11th, 1895, after an illness of but five days.

Mr. Phelps was the only son of the late George May Phelps, Sr., and was born at Troy, N. Y., in 1843. He was educated in the public schools and high school of that city. Since 1861, he had been continuously engaged in electrical interests, excepting for an interval of five years. He was first employed in the shop of the American Telegraph Company, of which his father was superintendent. He afterwards served the Auditing Department of the American Telegraph Company from 1863 to 1866. From 1871 till 1879 he was assistant to his father in the management of the factory of the Western Union Telegraph Company in New York City. In April, 1879, the Western Union Company disposed of its manufacturing interest to the Western Electric Company, and Mr. Phelps was appointed superintendent of the factory by the latter organization, which position he held until December, 1885. In August, 1886, he joined Mr. Franklin Leonard Pope in conducting *The Electrician and Electrical Engineer*, at that time published monthly, acquiring a proprietary interest in that journal shortly after. The title of the journal was subsequently changed to *The Electrical Engineer*, and beginning April 2d, 1890, it was issued weekly, the business being incorporated under the same title, with Mr. Phelps as President.

Mr. Phelps was a charter member of the American Institute of Electrical Engineers, and was elected one of its managers on May 19th, 1885. He served on the Council in this capacity until his election as Treasurer, on May 17th, 1887, to which office he has been re-elected each year, and which he held at the time of his decease. He had been nominated for the same office by

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Geo. M. Sheepo — Treasurer.

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the Council for the term beginning May 14th, 1895. He had also served on various standing and special committees, and has at all times readily given his time and services to the interests of the society.

FRANZ SCHULZE-BERGE, Ph. D., [*Associate Member, February 7th, 1890, Member, April 21st, 1891,*] was born January 2d, 1856, in Ober-Cassel, Germany. After graduating from the Gymnasium at Bonn, he studied mathematics and physics in the universities of Heidelberg and Strasburg, and then worked, principally under the guidance of Prof. von Helmholtz in Berlin. In 1880 he took the degree of Ph. D. in Berlin, for which degree Profs. Kerchoff and von Helmholtz were his principal examiners. Under the guidance of Prof. von Helmholtz, Dr. Schulze-Berge conducted, after methods of his own, experimental researches concerning the contact potential difference between metals and gases. The theme of his dissertation was of especial importance scientifically, since in physical investigations this potential difference is nearly always present as a disturbing element, as all metals are, generally speaking, in contact with gases.

His investigations involved the greatest nicety of manipulation and his methods evinced great originality. It was for his thesis on this investigation that he received his degree of Doctor of Philosophy.

Almost simultaneously with his work, the results of a similar investigation by another party were published, which disagreed with those obtained by Schulze-Berge. The latter at once prepared another paper in which he proved the correctness of his own conclusions and the error of those reached by the other author.

After graduating, in 1880, he passed an examination for Ober-Lehrer and occupied this position at the Louisenstaedtisches Gymnasium at Berlin, and that of Gymnasial-Lehrer at the Gymnasium at Charlottenburg.

He also, during this period, became a member of the "Berliner Physikalische Gesellschaft," and as such had charge of the official annual reports on different branches of electrical science, which were published in the *Fortschritte der Physik*, edited by the society, and at the same time continued electrical work in the laboratory of Prof. von Helmholtz. It was at this time that he was a co-worker with the late lamented Heinrich Hertz. He next turned his attention to the investigation of the electric con-

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ductivity of so-called non-conductors in very thin films (of $\frac{1}{10}$ of a millimeter or less). The results of these investigations and others are published in *Weidmann's Annalen*, vols. xii. and xv. and in the *Sitzungsberichte der Berlin Physikalischen Gesellschaft*, 1880.

In 1887, Dr. Schulze-Berge came to this country and became assistant to Mr. Thos. A. Edison. Perhaps the most notable of his work with Edison was the solution of the problem of duplicating phonographic records which was intrusted to his care. The method employed of producing a conducting film upon the wax cylinder of such a character as not to sensibly obscure or modify the finest harmonics, was the result of long study and experiment, and evinced the originality of the man. It was an entire success.

Leaving the employ of Mr. Edison, he retired to Brooklyn, where for the past year or two of his life he was engaged in his own private laboratory in physical investigations of various kinds, the results of some of which will doubtless soon be published. One of the results of his recent work has been a rotary mercury vacuum pump, an earlier form of which he described in a paper before the International Electrical Congress at Chicago in 1893. This has been still further improved upon, and adapted to the exhaustion of lamps, but the new form has not yet been described.

Dr. Schulze-Berge had long been suffering from an organic disease, the exact nature of which was not known until after his death. He died suddenly in Brooklyn on March 21, 1894, of diffuse nephritis, in the 39th year of his age.

Personally he was of a very retiring disposition and a man of such extreme modesty, that his nature recoiled from notoriety of any kind. For this reason he was less widely known than he was entitled to be through his natural gifts and his contributions to science. He rarely contributed to the technical press except to give the results of some important investigation. He broke away from this rule which he had made for himself, however, shortly before his death, the occasion being the contribution to one of the electrical journals of a biographical sketch of his friend Heinrich Hertz. This was his last appearance in print.

Though he did not count a very wide circle of personal friends, his manner was so kind, so gentle, and so evidently sincere, that none came within his influence but to love him, to admire him, to respect him, both as a man and a scientist.

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ALEXANDER HENRY BAUER, [*Associate Member, February 7th,* 1890, *Member, April 21st,* 1891,] who since 1882 had been actively engaged in practical secondary battery application for light and power purposes, died in New York City, January 15th, 1895, of Bright's disease. He passed away quietly and suddenly, while apparently in full possession of his reasoning faculties. Mr. Bauer, who was born in Baltimore, August 9th, 1846, had spent his working life in electrical pursuits, due possibly to hereditary traits, his father, William Henry Bauer, having been in service on the original Baltimore and Washington line of Prof. Morse, and he was also a friend and admirer of Prof. Henry. "Aleck," as he was familiarly called by his many old-time friends, entered the service of the Baltimore and Ohio Railroad Company in 1859, as a messenger boy. In that capacity he learned telegraphy, and at the beginning of the civil war, was sufficiently advanced to be assigned to regular duty at the Annapolis Junction office. Up to the year 1864 he was actively engaged as a telegraph operator, in the government as well as railroad employ, in various West Virginia offices, and afterwards entered the service of the United States Telegraph Company at Philadelphia. He subsequently returned to Baltimore, where he was employed by the Bankers and Brokers' Telegraph Company, and latterly by the Western Union, where he was appointed manager of the Commercial News Department, which included the "ticker" service. Upon the completion of the lines of the Mutual Union Telegraph Company, he was appointed manager of the Baltimore office, but after the amalgamation of that company with the Western Union, he gave up telegraphy, which, in his opinion, no longer offered a field for advancement.

The importation from Europe of 60 cells of the Faure secondary battery, in 1882, offered him an opportunity to enter upon what proved to be his future branch in the rapidly growing field of electric lighting. In a paper on "Secondary Batteries for Light and Power," before the INSTITUTE[1], presented May 16th, 1886, Mr. Bauer gave a very interesting history of three years practical experience, based upon the introduction of the Faure battery in electric lighting, street railway and telegraph service. This paper was of especial value at the date when it was written, as very little information upon the subject treated was accessible. He continued in this line of work with the Electric Storage

1. TRANSACTIONS, vol. iii, p. 129.

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Company, of Baltimore, and the Electrical Accumulator Company, New York, until 1888, during which period he became more generally known in the rapidly growing ranks of the electrical fraternity. The introduction of the secondary battery for the lighting of railroad trains led to his appointment, on February 18th, 1888, as electrical engineer of the Pullman Palace Car Company, a position which he held at the time of his death. At the Chicago meeting of the INSTITUTE, June 6th, 7th and 8th, 1892, Mr. Bauer read a paper[1] on "Railway Train Lighting," containing a description of the system used in the Pullman service, together with valuable data as to the cost of lighting, made up from actual records. These two papers by Mr. Bauer are characteristic of the man, and showed how thoroughly he had mastered all the details of the actual merits of the secondary battery for the service with which he had been most prominently identified.

In thus giving the public, through the INSTITUTE, the benefit of his investigations extending over a decade, Mr. Bauer performed a service which is no doubt appreciated by all whose duties have led them in similar directions. He also made many improvements in train lighting, some of which were patented. Recently his headquarters were at Jersey City, where he was enabled to personally supervise the apparatus on such through trains to the south and west as were provided with electric lighting plants. Mr. Bauer had a wide circle of friends who were warmly attached to him, all of whom were deeply shocked by his death, not being aware of the fatal character of his illness. He leaves a widow and a son, William F. Bauer, who, following the example of his father and grandfather, is also engaged in electrical pursuits, and who was elected an associate member of the INSTITUTE, April 15th, 1890.

RUDOLPH EICKEMEYER [*Associate Member, September 20th*, 1893, *Member, April 18th*, 1894] was born in Altenburg, Palatinate, Bavaria, October 18th, 1831, and was educated at the Polytechnic Institute, Darmstadt, Hesse. In 1850 he came to the United States and was first employed on the Erie Railway, and shortly after in the Buffalo Steam Engine Works. On the first of September, 1854, he established himself in business at Yonkers, N. Y., first as a repairer of tools, and subsequently as an inventor and manufacturer of hat machinery. Mr. George

1. TRANSACTIONS, vol. ix, p. 445.

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Osterheld, who came from Europe with him, was his partner in this business. Before interesting himself in electrical work in 1878, he had taken out about 150 patents. He continued his electrical experimenting and investigating, at first in the line of telephony, and in 1882 invented the type of dynamo which has since been known by his name. He began its manufacture for commercial use in 1886.

Owing to its compact form and high efficiency, this ironclad dynamo has been found especially adapted for railway train lighting. The motor proved equally desirable for street railway work, and its plan of winding was used in the Edison system. Mr. Eickemeyer devoted his attention especially to the magnetic qualities of his dynamos, and in the course of his investigations in 1887, he devised the differential magnetometer which proved of great service in determining the relative merits of different kinds of iron. Working alone as he did, and deriving his electrical knowledge from books, he naturally felt somewhat diffident as to the merits of his inventions. It was not until he had been assured by Mr. Stephen D. Field, that his electrical machinery was of a superior quality, that he decided to place it on the market. Even as late as 1893, when his inventions were well-known and appreciated, he was loth to admit that his work was worthy of consideration. "I am only a maker of hat machinery" were the words he used when asked about his electrical career. In the city of Yonkers, where he had built up a prosperous business, and among his friends who knew him best, his public spirit and genuine worth were highly respected and appreciated. Mr. Eickemeyer died at Washington, D. C., on January 23rd, 1895.

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FRANKLIN LEONARD POPE.

IN MEMORIAM.

On October 13th, 1895, in the picturesque village of Great Barrington, that nestles like a gem amidst the grandeur and beauty of the Berkshire Hills of Western Massachusetts, there occured one of the most tragic events that has so far attended the development of electric energy. In this, his birthplace, and scene of his childhood, Franklin Leonard Pope, at the age of 55 years, passed beyond the boundary that separates the known from the unknown. In the very prime of life, at the zenith of a most honorable and useful career, he was instantly stricken down by the mysterious electric agent that he had so thoroughly studied, and assisted to guide into the service of mankind at an early day, when but little was known of its subtle nature and useful possi bilities.

Mr. Pope was born on December 2nd, 1840, a descendant of Thomas Pope, the Pilgrim, who settled in Plymouth, Mass., in 1631, and died in Dartmouth in 1683, and it was the hereditary strain of Puritan energy that dominated Franklin Leonard, the subject of this fragmentary and inadequate sketch. His birth was almost coincident with the introduction of railroads and telegraphs, and so keen were his faculties of observation and interest in mechanism, that, when a small boy, he made from memory water-color drawings of all the locomotives on the Housatonic Railroad. Those pictures were such faithful reproductions, that Mr. Peleg Bronson, one of the engineers of that road, employed Master Pope to make a water-color picture of the locomotive "Lee." Thus his first earnings were due to the early development of his artistic taste, which was a characteristic trait throughout his career. It seems that the Christian name "Franklin" was singularly prophetic so far as Mr. Pope's tastes for scientific research were concerned.

After receiving such limited education as the common school of his native village afforded, supplemented by a term at the

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Franklin Lima

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Franklin Leonard Pope

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academy in Amherst, Mass., we find him at the age of 17, favored by the unsolicited appointment as operator in the Great Barrington telegraph office, and shortly afterwards appointed circuit manager of the Boston and Albany railroad wires at Springfield, Mass., as he soon attained considerable reputation as an expert operator of the Hughes printing instrument.

About the close of 1859, Mr. Pope was given a position in the drafting department of the *Scientific American* in New York City. Here he found scope for his natural talents as a draftsman, and at the same time acquired an insight into patent law and the preparation and prosecuting of applications for patents, a knowledge that he afterwards turned to good account.

Mr. Pope re-entered the telegraph service in Providence, R. I., as an operator, in 1861. There he displayed his drafting skill by making a complete map of all the wires and routes between Boston and New York, which was brought to the attention of General Marshall Lefferts, Engineer-in-Chief of the American Telegraph Company, who promoted him to a more important position in New York, where a larger field of usefulness opened out before this ambitious young man. During the draft riots in New York, in July, 1863, the telegraph wires were cut down by rioters, leaving the city in telegraphic darkness at a very critical moment in our country's history. Mr. Pope was assigned by General Lefferts to the duty of restoring communication between New York and Boston. The lines were found destroyed in many places along the railroad between Williams Bridge and 42nd Street in New York, and also in the southern portion of Westchester County, all that territory being under the surveillance of the rioters. Mr. Pope disguised himself as a farm laborer, and with a portable telegraph instrument and repairing tools concealed in a sack of oats, started from New Rochelle, and protected by a dark foggy day, walked over the fifteen miles between that place and Harlem River, and during the succeeding night connected up one of the fragmentary wires and restored telegraphic communication to Boston, notwithstanding he had to run the gauntlet of the enemy's pickets. At one time during the night he was captured, but so well did he play his role of a rustic, that he was liberated unharmed; at another time, a little later, he was attacked at a point near Morrisania by a gang of at least fifty rioters, armed with knives and pistols, but he eluded his assailants in the darkness by concealing himself in a cornfield

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until he was able to proceed unnoticed and complete his dangerous task. The single wire so connected, ran along fences; under station platforms, and was carried mainly by trees and bushes close to the ground, so that it was not distinguishable from the wrecked wires cut from their regular supports on poles. Thus was restored an unsuspected avenue of telegraphic communication that was of great public importance.

At the close of 1863, the telegraphers of the United States formed the National Telegraphic Union, of which Mr. Pope was the New York District Secretary. This society established a monthly publication, *The Telegrapher*, which, besides the aims and interests of the Union, was largely devoted to telegraphic history and progress, and contained many valuable and selected articles. Mr. Pope was the first contributor, under the pseudonym of "Elektron," of original researches upon batteries, repeaters, insulators and kindred subjects, in which connection the editor in the issue of April 25th, 1865, says: "The series of "articles upon "The Telegraphic Repeater," which has occupied "the first page of several numbers of this paper, are brought to "a close in this issue. The writer of them (Major Pope) has "done a signal service to our readers, the telegraphic public, the "inventors and ourselves. Never before has the subject been "printed. The diagrams were put upon the wood by Major "Pope, who has besides all this contributed freely to other "columns of this paper, and will be its correspondent from the "Collins' Overland expedition, whence he sailed in company "with Mr. Cran, on the 3rd instant, on the steamship 'Ariel,' "via the Isthmus."

Several illustrations of Mr. Pope's cleverness at designing and drawing are to found in *The Telegrapher's* pages, one of which appeared at the head of its editorial columns on Nov. 28, 1864, and another, the heading of the first page. This was designed to be symbolical of telegraphy, and is explained by the editor as follows: "The great joy of the 'owl' in the vignette while "sending his last message at midnight, can be readily under-"stood by those whose misfortune it is to see the day die and "come to life again, as they wearily drag themselves home from "a night's exhausting work. The scene at the right is the in-"terior of an office containing those wonders of telegraphy—the "printing instruments. Those who have witnessed the excite-"ment caused by news from the war can understand the pictured "scene at the left." [A crowd around a bulletin board.]

The overland telegraph connecting San Francisco and adjacent territory with Chicago and the East, was completed in October,

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1862, and the California State Telegraph Company had shortly afterward connected San Francisco by wire with New Westminster, in British Columbia.

Owing to the failure of Cyrus W. Field's 1858 cable under the Atlantic ocean, a project equally as stupendous was conceived by Perry Mc D. Collins, to connect the new and old worlds by the electric wire, via New Westminster northward through the Arctic region to Behring Strait, over 2,500 miles, crossing the Strait by a submarine cable about 178 miles in length, thence by overland wire through Russia to Moscow, about 7,000 miles. Owing to the extremely irregular Pacific coast line between Vancouver's Island and Cape Prince of Wales—deeply indented with ragged fiords, flanked by abrupt mountain ranges and spurs that stand sheer to the sea, beetling o'er their base and looking many fathoms down, it was necessary to find an interior route through British Columbia and Russian America (now Alaska), to Behring Strait. This region was nearly as trackless and vast as the ocean, with but vague accounts of the topography of a very limited portion gained through Indian hunters.

The Western Union Telegraph directors in 1864 organized the Western Union Russian Extension Company to carry out this gigantic enterprise, of which Colonel Charles S. Bulkley, who had been superintendent of military telegraphs in the Gulf Department, was appointed Engineer-in-Chief, and Mr. Pope Assistant Engineer and Chief of the Geographical Department. Among the preparations for the expedition to explore the country and construct lines through a region, the most of which was wholly unknown, it was necessary to make a very exhaustive study of all the existing charts, maps, books and other printed matter relating to British Columbia and Russian America. From these meagre sources, dating back to 1779, were compiled some important maps for the use of the leaders of the expedition. Mr. Pope executed on the polyconic plan a large map containing portions of the two hemispheres in a manner never before shown. Eminent geographers of that day considered the map a *chef d'œuvre* of drafting, and the most accurate map extant.

Mr. Pope was detailed to explore the wildest and most inhospitable portion of the territory between the head of the Fraser river in British Columbia and the Yukon river in the heart of Russian America, a distance of 1,500 miles, and in view of his qualifications for so important an undertaking, he was com-

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missioned with the rank of Major by Governor Andrew of Massachusetts, and attached to his staff. This compliment from Mr. Pope's native state is one that was creditable alike to both parties. Mr. Pope arrived in San Francisco on the 27th of April, 1865, and shortly after proceeded to New Westminster, whence he started, in June, northward upon his perilous undertaking. From New Westminster to Quesnel, about 390 miles north upon the Fraser river, the route was considered as a comparatively easy one for the construction of the line—and work had already been started upon this section by Assistant Engineer Edward Conway, the first pole being set on February 24th. The nature of this part of the country may be gleaned from a letter written at the time by Mr. Pope, who says: "The Colon-"ial Government is now engaged in cutting a road from New "Westminster to Yale, a distance of 90 miles, along which the "wire will be carried. There has heretofore been no communi-"cation between these two points whatever. The river (Fraser) "is bordered on both sides by high mountains and dense forests "of heavy timber with an almost impenetrable undergrowth."

"Notwithstanding these difficulties, Mr. Conway, during the "last part of last winter, made an exploration of the entire route "upon snow-shoes, a feat never before attempted by any white "man."

Mr. Pope also says: "It will be a matter of considerable diffi-"culty to construct a line of telegraph over that portion of this "road which passes through the 'Great Cañon,' as in many "places the road has a perpendicular wall of rock upon one side, "and a perpendicular precipice on the other, and in one place is "carried around the face of a cliff in this manner at an elevation "of some 2,000 feet directly over the river, being in some parts "blasted out of solid rock and in others supported by a sort of "staging."

There is nothing in this description of the first step in the enterprise calculated to reassure or cheer the hardy explorer who was bound northward into an Arctic country that was an absolute *terra incognita*, even to the adventurous fur trader of the Hudson Bay Company. This rugged, mountainous, volcano-torn and tossed rock-ribbed wilderness, presented tremendous impediments to exploration, which involved weary months of climbing over towering rocks and mountain ridges, precipices, through swamps, fording cold and dangerous streams—ever and anon scrambling over ragged promontories of river banks or skirting their bases with but slender foothold, amidst the defile of lofty mountains clad in perpetual snow. Such physical difficulties demanded a

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courage and endurance that but few men possess. Oft-repeated attempts would be made to find a passage over the mountains, but impassable barriers would as often turn back the explorers. A practical path at times seemed to be opened up by a defile, but only to terminate in a chaotic and impenetrable mass of cliffs and boulders, causing many painful retreats amidst the Arctic cold and snow, many times with scant food and no shelter. It was under such conditions that Mr. Pope carried on his explorations from June, 1865, to May, 1866. He succeeded in surveying the route as far north as the head-waters of the Stikeen river, which are about 1,100 miles from New Westminster, and 200 miles from the Pacific ocean. Arriving there in the middle of April, it was found necessary to stop explorations until the following winter on account of the approaching mild season, the snow being necessary to enable the explorer to travel over dense underbrush and other obstacles so graphically described by Mr. Pope in a private letter written from Lake Tatla, B. C., Nov. 7th, 1865, as follows:

"I have just returned from an exploring expedition north to "Fort Connolly, about sixty miles from here. We had to carry "our blankets, provisions, axes, frying-pans, guns and forty "other traps on our backs, and the whole forest from here to "there has been burnt, and has all blown down, and the logs "are piled up 'criss-cross' in every direction several feet high, "like a pile of matches thrown on the floor. It was nice work "climbing over that pile of stuff for over sixty miles with the "load we had. Then we had to wade a river, nearly twice as "large as the Housatonic, about daylight one morning, with the "ice running down. To add to the beauties of the situation, we "got snowed up in the mountains, and had to stay there until all "our 'grub' was eaten up, and when we finally got out, had to "travel all the way back again with nothing for three of us to "eat, except two dried wood-chucks and four dried fish. We "used to scramble over the logs all day and sit down at night "and eat our pieces of dried wood-chuck, about as large as a "plug of tobacco and a good deal tougher than gutta percha, "with first rate appetites."

In another letter, dated New Westminster, June 15, 1866, Mr. Pope gives us a sample of his power of description, as well as an insight into the trying task he had set out to accomplish after he left Lake Tatla to reach the head-waters of the Stikeen, as well as his adventurous trip down that river to the ocean, on his way to New Westminster, to perfect plans and arrange for supplies to resume explorations in the wilderness northward between the Stikeen and the Yukon rivers. He says:

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"The little party was composed of two white men, Mr. George "Blenkinsop, of Victoria, and myself, with two Indians to assist "in cutting firewood and carrying the provisions. We were "furthermore provided with a sledge and team of four dogs, "which, when we set out, carried four hundred pounds of pro-"visions and other necessary articles. Each of us was also "furnished with a pair of snow-shoes, without which one could "not move ten rods from home in the deep snows of this north-"ern climate. Thus equipped, we set out on our journey into "the unknown wilderness, with no guide but the compass, and "the certainty that the river Stikeen lay at an unknown distance "to the northwest. Our greatest difficulty was caused by the "depth, and more especially the lightness of the snow, in which "the dogs would sometimes struggle for an entire day, with "merely their heads above the surface, we drawing the load our-"selves, and sometimes even carrying the dogs on our backs, when "they were too much exhausted to move. For many days we "thus laboriously worked our way up the valley of the Skeena, "making an advance of only three or four miles per day with "the utmost labor and difficulty. The snow in many parts of "this valley was ten feet in depth."

"On the 23rd of March we reached the head of Skeena river "in a beautiful prairie about 15 miles in length and surrounded "by lofty, snow-clad mountains. Here we were obliged to kill "one of the dogs which was worn out with the severe labor, and "unable to keep up with us. Matters thus far had been any-"thing but encouraging. After a month of protracted and very "exhausting labor we had accomplished but 150 miles, and our "dogs were nearly all 'used up,' and in a fair way to soon follow "the first one killed, which would leave us without any means of "transportation for our provisions in the heart of an intermin-"able wilderness. We two, excluding the Indians, who, of "course, wanted to return, held a council of war, at which it was "unanimously decided to 'go ahead.' So we pushed forward, "and from that moment circumstances favored our enterprise. "The snow became firm under our feet, and the three dogs "trotted along merrily with the load over its smooth, hard sur-"face. We were now following a stream which I knew from "the nature of the country must be a tributary of the Stikeen, and, "indeed, it was the identical river itself. So we pushed forward "as rapidly as possible, and about the 15th of April came upon "the encampment of an Indian family, who had, fortunately, "just killed a reindeer, and were, consequently, flush of provis-"ions. They treated us with the utmost hospitality, and we "gladly accepted their invitation to remain a day or two and "feast ourselves and our half-starved dogs. So we lay on the "fragrant bed of spruce boughs in the Indian wigwam, enjoying "the unaccustomed luxury of having plenty to eat and nothing "to do. Our dusky hosts were continually cooking all kinds of

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"strange messes, and inviting us to partake of them, which, in "accordance with Indian etiquette, we invariably did and asked "no questions. At night we slept in the wigwam, mixed up in-"discriminately with the whole family—men, women, children, "babes and "cultus" dogs—seventeen humans and an indefinite "number of curs, packed in a space of about 15 feet square. "However, the building, being constructed of fir boughs, was "well ventilated, and we experienced no particular inconven-"ience."

"The next morning we bade farewell to our hospitable enter-"tainers, and, harnessing our dogs, proceeded on our journey. "In a day or two more we reached the Grand Cañon of the Stik-"een—a place which had been visited by the miners from the "lower river in 1862. Avoiding the worst part of the cañon by "an overland portage of 40 miles, we entered the lower part of "it by a side gulch at Salmon creek. Language cannot describe "the overpowering and terrible grandeur of the scene in many "parts of this cañon. It may be described as an immense fissure, "apparently caused by an earthquake, 80 miles in length, and "running through a comparatively level country. This chasm, "though in no place over 200 or perhaps 300 feet wide, varies "in depth from 300 to 2,000 feet. The walls are in most places "perpendicular, and wrought by the hand of nature into the "most curious forms and colors. Through the bottom of the "cañon the river rushes furiously along, filling the whole space "between the walls. The river had been frozen several feet "thick, but had broken away in the middle, leaving the firm ice "still clinging to the rocky walls, and along this we made our way "for 30 miles. In several places the ice was gone entirely, and "we were obliged to clamber perilously up and along the per-"pendicular cliffs overhanging the waters, hauling up the dogs "and baggage with ropes."

"By great care and patience, all these difficult and dangerous "places were finally passed without accident, and to our great "relief we came out from beneath the gloomy and frowning "ledges of the cañon into the sunlight once more. Reaching "Buck's Bar, the seat of the celebrated Stikeen gold excitment "of 1862, we built a boat,—not a handsome boat, but still a "boat,—out of lumber left there by the miners, and waiting a "day or two for the ice to run out of the river, we lauched our "craft. which was christened the 'Clarette,' and set out for the "Pacific. The powerful current of the Stikeen, aided by our ef-"forts with the oars, in three days carried us over 160 miles inter-"vening between Buck's Bar and the 'great salt sea.' Arriving "at the mouth of the river, we found the steamer 'Otter' an-"chored in the offing, bound next day for Victoria. We rowed "out to her and went aboard at once, glad enough to see the "faces of white men once more after our toilsome journey "of seven hundred miles, which was accomplished in seventy "days."

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The difficult nature of this undertaking was well understood by his brother, Mr. Ralph W. Pope, then stationed at Quesnel, who wrote in his diary, March 5th, as follows:

"Hudson Bay express, 12 days from Fort James, arrived, "bringing letters from my brother's party, the latest dated Lake "Tatla, January 22d. Major Pope and Blenkinsop were to start "for the coast, via Connolly's Lake, on the 1st of February. I "think it doubtful whether they succeed in reaching there, but "if they do, they will probably reach New Westminster by the "1st of May."

[As a matter of fact, they left Tatla February 19th, and arrived at New Westminster May 24th, 1866.]

The *Alta-California* commented at the time upon Mr. Pope's achievements as follows:

"Major Pope has shown great energy in pushing this survey "through, resulting so favorably, and is entitled to much credit "for his tact and skill in the management of the various Indian "tribes in the Northwest, with whom he is on the most friendly "terms."

His success with these treacherous nomads was foreshadowed at the outset. Mr. Pope called a grand council of the Indians, at Fraser lake, and explained to them the object of his trip through their country, and in order to convey to their minds some idea of the nature of the telegraph, he strung a wire upon small poles, a distance of several hundred yards, and made a circuit with a portable intermediate battery, and pocket instruments. At one end of the wire, Mr. Pope arranged a pistol in such a manner that it was fired by the Indian chief closing the distant key. This performance was voted "great medicine," and was repeated many times, to the wonder and delight of the savages. The chief stationed some of his braves at the farther terminal of the circuit, to which end Mr. Pope also repaired, and without their knowledge the chief had Mr. Pope's brother, Ralph W., transmit a message asking for a piece of tobacco, which was promptly conveyed by a courier and presented to the chief, causing great astonishment and an immense outburst of "Chinook" jargon. This admirable "medicine" together with very generous gifts, particularly tobacco, the acme of an Indian's desires, had a propitiatory effect, and elevated Mr. Pope to a high pinnacle in the savage esteem.

While Mr. Pope was arranging the details at New Westminster,

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to explore the more difficult and dangerous part of his territory northward to the Yukon River, to meet an exploring party already started from its mouth to pierce the interior, and form a junction at its head-waters with Mr. Pope, he received the intelligence of the success of the Atlantic cable, and with his intimate knowledge of telegraph affairs, and his late experience, he wisely concluded, in advance of the executive officials of his company, that the Russian overland enterprise was doomed for a long time to innocuous desuetude, and resigning his position, he reached New York in October, 1866. His record from that time on is one of close and intelligent study of law, and the complete circle of scientific subjects, and more particularly the application of electricity to telegraphy, railroad signals, and the numerous other industrial and domestic purposes.

Immediately upon his return, Mr. Pope resumed the contribution of original illustrated articles to *The Telegrapher* upon the method of working the Atlantic cable; the principles of duplex working, and other practical subjects of great moment to the rank and file of American telegraphers, who had, outside of that journal, but very meagre sources of information.

Mr. Pope ably filled the editor's chair of that paper from August, 1867, until February, 1868, when he resigned to devote himself to electrical engineering. In 1867 Dr. S. S. Laws invented an electrical instrument intended to exhibit the changes in the market prices of gold in brokers' offices and to be operated by wires from the gold exchange. The invention was entirely tentative until 1868, when Mr. Pope was secured to develop and manage the system, which, through his ingenuity, was soon placed in satisfactory operation, netting a large profit to the proprietor, besides laying the foundation for the immense stock reporting system of the present day.

In this year Mr. Pope commenced work upon the first edition of his "Modern Practice of the Electric Telegraph" which was issued in May, 1869, and advance sheets were thus commented upon by the Western Union *Journal of the Telegraph*, of February 1st, 1869:

"We are not a little pleased to know that in about a month a "book entitled 'The Modern Practice of the Electric Telegraph' "will be published. The author is Frank L. Pope, widely "known as a clear-headed, practical, educated expert. He has "devoted to the work great labor, and has illustrated all his "topics, which were susceptible of it, by elegantly executed en-

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"gravings, or cuts, and has followed exhaustively in his usual "clear and succinct style the whole of the practical telegraphic "operations."

This book met with instant favor both here and abroad, was translated into foreign languages, and up to the present time has run through 15 editions, each of which Mr. Pope enlarged to fully cover, at its date of issue, the latest developments in the art.

Mr. Pope resigned his position with the Laws Gold and Stock Reporting Telegraph in July, 1869, and shortly afterwards formed a partnership with Thomas A. Edison and James N. Ashley, under the style of Pope, Edison & Co., Electrical Engineers, with offices at 78 and 80 Broadway, New York. The first advertisement of this firm appeared in *The Telegrapher*, October 2, 1869, and its object was stated to be, to give professional attention to a variety of subjects, involving the use of electricity, also to patent applications, drawings, wood engraving, etc. Mr. Ashley was at that time editor of *The Telegrapher*, and Mr. Edison, in March, 1869, had resigned as operator in the Western Union Telegraph office at Cincinnati, Ohio, and accepted a similar position with the same company in Boston. He had about this time invented a system of duplex transmission described and illustrated in *The Telegrapher* on April 11th, and complete sets were advertised for sale by Mr. Edison in December, 1868. The following January he resigned in Boston, and came to New York to devote himself entirely to electrical inventions and became Mr. Pope's partner as above stated. The firm, after a brief existence, was dissolved in 1870, as was naturally to be expected by those who knew the make-up of its members. A joint patent on a single-wire printer, subsequently sold to the Gold and Stock Telegraph Co., was a familiar factor in patent litigation where it was generally known as the "Pope and Edison patent." The inventive genius of both Messrs. Pope and Edison led them into the same field, and it was inevitable that whatever discoveries, devices or suggestions they made, would be difficult to satisfactorily allot.

Mr. Pope from this time on continued actively engaged in inventions and electrical engineering. He secured several patents, the majority of them being for a railroad semaphore block signal system, to fill a great need upon our trunk lines. He brought to bear on this important subject an exhaustive knowledge of it, together with good practical ideas, reinforced by his usual ener-

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getic application, which eventually resulted in the successful development of a reliable system.

In 1875, Mr. Pope was appointed patent expert and counsellor of the Gold and Stock Telegraph Company, and shortly afterwards to a similar position with the Western Union Telegraph Company.

In 1880, the astounding developments in the introduction of electricity for light, power and heat, and to various other important uses, attracted capitalists at a time when capital was plenty. Patents in this branch of industry were being issued by the thousand, and there was a great demand for expert knowledge to guide and protect the large resulting investments. Realizing this state of affairs, Mr. Pope established himself as a patent lawyer, solicitor and electrical expert, with offices at 32 Park Place, New York City, and subsequently at 59, 11, and 15 Wall Street. He afterwards formed a partnership with his associates, which continued under different firm titles until 1894, Mr. Pope's name appearing always as senior partner.

Mr. Pope was a member of the British Institution of Electrical Engineers ever since its inception in 1872, also one of the first Vice-Presidents, and the second President of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. He was also elected Vice-President of the American Electrical Society of Chicago, in 1878, and during the following year contributed to its journal the ablest and most interesting paper upon the "Life and Work of Joseph Henry," that has ever appeared.

In this admirable tribute to Henry's transcendent genius and spotless character, Mr. Pope says:

"There is to me a singular fascination in tracing the footsteps "of the pioneers of science and discovery; in visiting the places "which have been the scenes of their struggles, their disappoint-"ments, and their triumphs; in handling the crude and roughly "fashioned apparatus, frequently the work of their own not un-"skillful hands; and in gathering from the lips of eye-witnesses "the anecdotes and reminiscences which tell the story of their "lives, and work, and studies."

"With such thoughts as these, I found myself one crisp, clear "autumn day, not many weeks ago (1878) strolling beneath the "venerable elms that shade the campus, and droop their branches "lovingly over and around the classic halls of Princeton."

A key is here furnished to the inspiration of so many of Mr. Pope's articles, particularly to the notable one in the *Electrical Engineer* of 1891, upon "The Inventors of the Electric Motor."

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In 1884, Mr. Pope secured an interest in, and became the editor of the *Electrician*, which was started in 1882. He changed its name to *The Electrician and Electrical Engineer*, and continued to conduct it as a monthly electrical journal until 1890. Before retiring from its active management, the title was changed to the *Electrical Engineer*, and it was soon made a weekly. He also edited the electrical department of the *Engineering Magazine*. His very last literary work was a contribution to the latter, on the "Distribution of Electric Power at Niagara." He left the last sheet of this unfinished article in his typewriter the night before he died.

In his professional capacity during the past twenty years, he had been retained by some of the largest and most influential concerns in this country, among them the Postal Telegraph Company, the American Bell Telephone Company and the Westinghouse Electric Company, and it was mainly through his investigations and recommendation, that the latter company undertook the exploitation of the alternate current system, now so generally in use.

In the fall of 1894, Mr. Pope made an important change in his business plans, which had long been in contemplation. He had several years before acquired the title of the homestead at Great Barrington, and at considerable expense had converted the old brick house built in 1766 to a modern country mansion, which he named Wainwright Hall, in remembrance of his mother's family name, and the former owner of the property. While at Great Barrington he continued to serve his clients in the capacity of expert, and as a pastime also undertook to remodel upon the best engineering lines the plant of the Great Barrington Electric Light Company, utilizing the valuable water power of the Housatonic river. Of this important work a most interesting account was given by Mr. Pope in a paper read before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, June 26, 1895.

It is not too much to say, that to Mr. Pope, more than any other, are American telegraphers and electricians indebted for free enlightment upon subjects in which they were naturally interested, through his able contributions to the various electrical and scientific journals, encyclopædias and magazines of this country.

He had at all times shown the greatest interest in electrical

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organizations, as well as literature, believing thoroughly in the general welfare which followed the exchange of ideas through these channels. One of his strongest characteristics was his readiness to tender his advice and a helping hand to all with whom he came in contact, who were striving to acquire knowledge in the electrical field.

In 1886 Mr. Pope prepared for the Berkshire (Massachusetts) Historical Society, of which he was a member, a paper on the western boundary of Massachusetts, embracing a study of Indian and colonial history, and it is surprising to contemplate the painstaking research into the unpublished manuscript archives of the adjoining states, including county and town records, and the immense labor involved in the compilation of such a valuable history which is highly treasured by all interested persons.

Although firm in his convictions and intrepid in his statements, Mr. Pope was exceedingly unassuming. Above his intellectual attainments and skill, his integrity towered as unyielding as an Egyptian pyramid. He was conscientious and painstaking. To his keeping, his clients had frequently consigned immense confidential interests. He made their cause his own, and with a deep sense of responsibility, spared no efforts to base his advice or action, upon a complete knowledge of the underlying facts.

His electrical library was one of the best in this country, and his untiring industry in the pursuit of knowledge made him a frequent visitor to many of our similar public institutions.

As to Mr. Pope's qualities of heart, their correct exponent is found in the following incident. In 1881 one of his former business associates died, leaving an unprotected young daughter with limited means to face the world. Mr. Pope immediately sought the young lady and said to her: "Your father was my friend, and so long as I live, I shall be one to you." It is needless to add that this heaven-inspired promise was nobly kept.

F. W. J.

New York, February 7th, 1896.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

CATALOGUE OF MEMBERS.

MARCH 1ST, 1896.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
KELVIN, *Lord*,	*LL.D.*, *F.R.S.S.L.* and *E.* The University, Glasgow, Scotland,	H.M. May 17, 1892
PREECE, WM. H. *F.R.S.*	Electrician, General Post Office, London, Eng. Residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

Total, 2.

MEMBERS.

ABBOTT, ARTHUR V.	Chief Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Oct. 21, 1890 M Jan. 16, 1895
ACHESON, EDW. G.	Electrician and Electrical Engineer, Carborundum Co., Monongahela City, Pa.	A Jan. 3, 1888 M May 1, 1888
ADAMS, ALTON D.	Electrical Engineer, 620 Atlantic Ave., Boston, Mass.	A April 18, 1893 M Jan. 17, 1894
AHEARN, T.	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., New York; residence, 60 Sayre St., Elizabeth, N. J.	A Sept. 27, 1892 M June 20, 1894
ALMON, G. H.	Electrical Engineer and Contractor, 136 Liberty St., New York City, and 620 Atlantic Ave., Boston, Mass.	A Sept. 20, 1893 M Mar. 21, 1894
ANTHONY, PROF. W. A.	(*Past President.*) (*Vice-President.*) Consulting Electrician, Temple Court, New York, N. Y.	A Dec. 9, 1884 M Jan. 6, 1885
ARNOLD, BION J.	(*Manager.*) Consulting Electrical Engineer, 1541 Marquette Bldg. and 4128 Prairie Ave., Chicago, Ill.	A Oct. 25, 1892 M Nov. 15, 1893

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Name.	Address.	Date of Membership.
AYER, JAMES I.	General Manager American Electric Heating Corporation, 611 Sears Building, Boston, Mass.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec. 16, 1891 M Mar. 15, 1892
BAILLARD, E. V.	Manufacturer of Electrical Instruments and Fine Machinery, 106 Liberty St., New York City.	A Dec. 3, 1889 M Jan. 16, 1895
BARBERIE, E. T.	Electrician, 159 W. 66th St., New York City.	A Jan. 19, 1892 M Oct. 25, 1892
BATCHELOR, CHAS.	Electrical Engineer, 33 West 25th St., New York City.	A June 8, 1887 M July 12, 1887
BATES, J. H.	Assistant Engineer and Draughtsman, with C. J. Bates & Co., 126 Liberty St., New York City, and 321 Hudson St., Hoboken, N. J.	A Sept. 6, 1887 M Oct. 1, 1889
BATES, MAURICE E.	Wilkes-Barre, Pa.	A Aug. 6, 1889 M Oct. 1, 1889
BAYLIS, ROBERT NELSON	Electrical Engineer, The Walker Manufacturing Co., Cleveland, O.	A Oct. 1, 1889 M May 17, 1892
BELL, PROF. A. GRAHAM	(*Past President.*) 1331 Conn. Ave., Washington, D. C., and Baddeck, N. S.	A April 15, 1884 M Oct. 21, 1884
BELL, DR. LOUIS	Electrical Engineer, Boston, Mass.	A May 20, 1890 M June 18, 1890
BENJAMIN, PARK	Electrical Expert and Engineer, 203 Broadway, N. Y. City.	A Dec. 16, 1891 M Feb. 16, 1892
BERNARD, EDGAR G.	Electrical Engineer, President, E. G. Bernard & Co., 43 4th St., Troy, N. Y.	A. Jan. 5, 1886 M July 12, 1887
BERTHOLD, VICTOR M.	Patent Department, American Bell Telephone Co., 125 Milk St., Boston; residence, 16 Upton St., Cambridgeport, Mass.	A May 17, 1892 M May 21, 1895
BILLBERG, C. O. C.	Electrical Engineer, 3200 Arch St., Philadelphia, Pa.	A Mar. 21, 1894 M Feb. 27, 1895
BINNEY, HAROLD	Patent Solicitor and Expert, Potter Building, 38 Park Row, New York City.	A Sept. 16, 1890 M Dec. 16, 1890
BIRDSALL, E. T. *M. E.*	Consulting Electrical Engineer, 18 Broadway; Residence, 56 West 38th St., New York City.	A June 8, 1887 M Nov. 1, 1887
BISHOP, JAMES DRAPER	Electrical Engineer of the Safety Insulated Wire and Cable Co., 234 W. 29th St., New York City.	A Dec. 16, 1891 M Oct. 25, 1892
BLADES, HARRY H.	General Superintendent, The Detroit Motor Co., 1343-55 Cass Ave., Detroit, Mich.	A April 19, 1892 M May 21, 1895
BLAKE, FRANCIS	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
BLODGETT, GEO. W.	Electrical Engineer, B. & A. R. R. and Consulting Electrician, Boston, Mass.	A July 12, 1887 M Sept. 6, 1887

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Name.	Address.	Date of Membership.
BLOOD, JOHN BALCH	Assistant Engineer, Railway Dept., General Electric Co., Schenectady, Y. N.	A June 20, 1894 M Dec. 18, 1895
BOSCH, ADAM	Sup't Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
BOSSON, FREDERICK N.	Consulting Mining and Electrical Engineer; Electrician, Calumet and Hecla Mining Co , Calumet, Mich.	A May 17, 1892 M Feb. 21, 1893
BOTTOMLEY, HARRY	Electrical Engineer, Supt., Marlboro Electric Co., Marlboro, Mass.	A April 2, 1889 M Jan. 22, 1896
BOURNE, FRANK	Electrical Engineer, 39 Cortlandt St., New York City.	A April 21, 1891 M Nov. 15, 1892
BOWMAN, FRED. A.	Supt., New Glasgow Electric Co , New Glasgow, Nova Scotia.	A May 19, 1891 M Nov. 21, 1894
BOYNTON, EDWARD C.	Mechanical and Electrical Engineer, P. O. Box 358, Erie, Pa.	A Aug. 6, 1889 M Nov 24, 1891
BRADLEY, CHAS. S.	(*Manager.*) Electrical Engineer, 10th Street, Cor. North Ave., Walbrook, Baltimore, Md.	A May 24, 1887 M Dec. 6, 1887
BRENNER, WILLIAM H.	Electric Storage Battery Co., Madison Ave. and 86th St., New York City.	A Sept 20, 1893 M Mar. 21, 1894
BROADNAX, FRANCIS	Electrical Engineer, Blake and Williams, 362 West Broadway, New York City; residence, 28 Walnut St., Montclair, N. J.	A Jan. 17, 1894 M Jan. 16, 1895
BROOKS, MORGAN	President and Manager, The Electrical Engineering Co., 249 Second Ave., South; residence, 2950 Park Ave., Minneapolis, Minn.	A May 20, 1890 M June 17, 1890
BROWN, ALFRED S.	Electrical Engineer, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	A Mar. 18, 1890 M Feb. 21, 1893
BROWN, EDWARD D.	General Inspector, American Telephone and Telegraph Co., 18 Cortlandt St , New York City; residence, 75 Hicks St., Brooklyn, N.Y.	A Sept. 19, 1894 M Nov. 20, 1895
BROWN, J. STANFORD, *E.E.*, [Life Member.]	Consulting Electrical Engineer; Carpenter Steel Co., 1 Broadway and 100 Broadway, New York City; residence, Park Hill, Yonkers, N. Y.	A Sept. 6, 1887 M Nov. 1, 1887
BRUSH, CHAS. F.	Electrical Engineer, 453 The Arcade, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
BURLEIGH, CHAS. B.	Supt. Isolated Dept. General Electric Co., 620 Atlantic Ave., Boston, Mass.	A April 21, 1891 M Feb. 16, 1892
BYLLESBY, HENRY M.	Northwest General Electric Co., 403 Sibley St., St. Paul, Minn.	A Sept. 7, 1888 M Oct. 2, 1888
CAHOON, JAS. B.	Electrical Engineer; General Manager, The Elmira Municipal Improvement Co.; 217 West First St., Elmira, N. Y.	A June 17, 1890 M May 19, 1891
CALLENDER, ROMAINE	Electrician, Decker Building, New York City.	A Sept. 27, 1892 M May 21, 1895

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Name.	Address.	Date of Membership.
CARROLL, LEIGH	Algiers Ice and Electric Co., 19 Elmira Ave., New Orleans, La.	A Oct. 1, 1889 M Nov. 12, 1889
CARUS-WILSON, CHARLES A.	Professor of Electrical Engineering, McGill University, Montreal, P. Q.	A April 18, 1894 M April 17, 1895
CHAMBERLAIN, J. C.	Electrical Engineer, Morris Heights; residence, 1 West 81st St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
CHANDLER, PROFESSOR CHARLES F.	Columbia College, 41 East 49th St., New York City.	A Jan. 20, 1891 M June 7, 1892
CHASE, HARVEY STUART	Mechanical and Electrical Engineer, 39 Cortlandt St., New York City.	A Sept. 19, 1894 M Jan. 22, 1896
CHENEY, W. C.	Superintendent and Electrical Engineer, Portland General Electric Co., Portland; residence, Oregon City, Ore.	A Sept. 22, 1891 M Nov. 21, 1894
CHILDS, ARTHUR EDWARDS, *B. Sc. M.E.E.E.*	Manager New England Office, The Electric Storage Battery Co., 333 Exchange Bldg., Boston, Mass.	A June 20, 1894 M April 17, 1895
CHURCHILL, ARTHUR	Engineering Dept., Schenectady Works. General Elec Co., 5 So. Church St., Schenectady, N. Y.	A April 15, 1890 M Jan. 17, 1893
CLARK, ERNEST P.	Electrical Engineer, Clark Electric Co., 478 Pearl St., New York City.	A Jan. 8, 1887 M Nov. 1, 1887
CLARKE, CHAS. L.	Electrical Engineer and Patent Expert, 55 Liberty St., New York City.	A April 15, 1884 M Jan. 6, 1885
COLBY, EDWARD A.	Consulting Engineer, Lock Box 313, Newark, N. J.	A April 2, 1889 M May 7, 1889
COLVIN, FRANK R.	President, Interior Telephone Co., 203 Broadway, New York City.	A April 18, 1894 M May 21, 1895
COMSTOCK, LOUIS K.	Electrical Engineer, Monadnock Building, Chicago, Ill.	A Dec 20, 1893 M Nov. 20, 1895
CONDICT, G. HERBERT	Electrical Engineer, 5328 Green St., Germantown, Pa.	A July 12 1887 M Sept. 6, 1887
CORNELL, CHAS. L.	Electrical Engineer, Hamilton, O.	A Feb. 7 1890 M June 27, 1895
COTHREN, WM. H.	51 W. 37th St., New York City.	A Aug. 6, 1889 M Oct. 1, 1889
COWLES, ALFRED H.	Technical Adviser to the Cowles Smelting and Aluminum Co., 656 Prospect St., Cleveland, O.	A Mar. 5, 1886 M May 7, 1889
CRAIG, J. HALLY	New England Electrical Supply Co., 49 Federal St., Boston, Mass.	A May 16, 1893 M Feb. 27, 1895
CRAIGIN, HENRY A.	Engineer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A June 6, 1893 M May 15, 1894
CRANDALL, JOSEPH EDWIN	Electrician, C. & P. Telephone Co., 619 Fourteenth St., N. W. Washington, D. C.	A April 18, 1892 M April 18, 1894

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Name.	Address.	Date of Membership.
CROCKER, FRANCIS BACON [Life Member.]	(*Vice-President*) Professor of Electrical Engineering, Columbia College, New York.	A May 24, 1887 M April 2, 1889
CROSBY, JAMES WELLINGTON	Electrical Engineer, 38 Bedford St., Boston; residence, Wellington, Mass.	A Feb. 21, 1894 M Feb. 27, 1895
CROSS, PROF. CHAS. R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
CUTTER, GEORGE	Dealer in Electrical Supplies, 851 The Rookery, Chicago, Ills.	A June 17, 1890 M May 19, 1891
CUTTRISS, CHAS.	Electrician, The Commercial Cable Co., 1 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
DAFT, LEO	Consulting Electrical Engineer and Contractor, Los Angeles, Cal.	A Dec. 9, 1884 M Jan. 6, 1885
DANIELL, FRANCIS G.	Electrical Engineer, Fairhaven and Westville R. R. Co., P. O. Box 394, New Haven, Conn.	A Nov. 12, 1889 M June 20, 1894
DARLINGTON, FREDERIC W.	Consulting Electrical and Mechanical Engineer, 907 Drexel Building, Philadelphia, Pa.	A Sept. 19, 1894 M Nov. 25, 1895
DAVIES, JOHN E.	Professor of Physics, University of Wisconsin, 523 North Carroll St., Madison, Wis.	A Jan. 7, 1890 M Mar. 18, 1890
DAVIS, CHARLES H., *C. E.*,	Consulting and Constructing Engineer, 99 Cedar St., 576 Lexington Ave., New York City, and 308 Walnut St., Philadelphia, Pa.	A Mar. 18, 1890 M June 17, 1890
DAVIS, MINOR M.	Ass't Electrician, Postal Telegraph-Cable Co., 253 Broadway, New York City	A April 6, 1886 M May 16, 1893
DELAFIELD, A. FLOYD, *Ph. D.*	Electrical Engineer, Noroton, Conn.	A May 7, 1889 M Oct. 1, 1889
DELANY, PATRICK BERNARD	Inventor, South Orange N. J.	A April 19, 1884 M Nov. 24, 1891
DICKENSON, SAMUEL S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N. S.	A Mar. 6, 1888 M Oct. 1. 1889
DIEHL, PHILIP	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
D'INFREVILLE, GEORGES	Electrical Engineer and Expert, 10 Desbrosses St., New York City.	A Nov. 1, 1887 M Dec. 6, 1887
DION, ALFRED A.	General Supt., The Ottawa Electric Co., 72 Sparks St., Ottawa, Ont.	A Jan. 7, 1890 M Nov. 15, 1893
DODGE, PROF. OMENZO G.,	U. S. Navy, Navy Dep't, Washington, D. C.	A Sept. 20, 1893 M April 17, 1895
DOIJER, H.	Consulting Electrical Engineer, 8 Choorstraat, Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
DOANE, S. EVERETT	68 Park Pl., Newark, N. J.	A Aug. 6, 1889 M June 27, 1895

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Name.	Address.	Date of Membership.
DONNER, WILLIAM H.	Eletrical Eng'g Dept. International Correspondence School, Scranton, Pa.	A Nov. 18, 1890 M Dec. 16, 1890
DOW, ALEX	Engineer, Public Lighting Commission, Detroit, Mich.	A Sept. 20, 1893 M Dec. 18, 1895
DUDLEY, CHARLES B.	Chemist and Scientific Expert, Penn. R. R. Co., 1219 Twelfth Ave., Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
DUNBAR, F. W.	417 West 23d St., New York City.	A Dec. 21, 1892 M May 16, 1893
DUNCAN, DR. LOUIS	(*President*) Johns Hopkins University, residence, 139 E. North Ave., Baltimore, Md.	A July 12, 1887 M Sept. 6, 1887
DUNN, GANO SILLICK	Chief Engineer, Crocker-Wheeler Electric Co., Ampere, E. Orange, N. J.; residence, 223 Central Park, West, New York City.	A April 21, 1891 M June 20, 1894
DUNSTON, ROBT. EDWARD	The Cortland and Homer Traction Co., Cortland, N. Y.	A Oct. 27, 1891 M Feb. 16, 1892
DYER, R. N.	Patent Attorney, 36 Wall St., New York City.	A July 12, 1887 M Sept. 6, 1887
EDISON, THOMAS A.	Mechanician and Inventor, Orange, N. J.	A April 15, 1884 M Oct. 21, 1884
EGGER, ERNST	Electrical Engineer care of B. Egger & Co, X., Simmeringstr, 187, Vienna, Austria.	A Feb 21, 1893 M Mar. 21, 1894
EMERY, CHARLES EDWARD	Consulting Engineer, 915 Bennett Building, cor. Fulton and Nassau Sts., New York City.	A June 26, 1891 M April 19, 1892
EMMET, W. L. R.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 6, 1893 M Jan. 17, 1894
EVEREST, AUGUSTINE R.	Electrical Engineer, General Electric Co., Lynn, Mass.	A May 19, 1891 M Dec. 20, 1893
FARNHAM, ISAIAH H.	Electrical Engineer, N. E. Telephone & Telegraph Co., 125 Milk St., Boston, Mass.	A June 8, 1887 M July 12, 1887
FESSENDEN, REGINALD A.	Professor of Electrical Engineering, Western University of Pennsylvania, Allegheny, Pa.	A Oct. 21, 1890 M Dec. 16, 1890
FIELD, C. J., *M. E.*	Consulting and Constructing Engineer, 39 Cortlandt Street, New York City.	A June 8, 1887 M Nov. 1, 1887
FIELD, STEPHEN D.	Electrical Engineer, Stockbridge, Mass.	A April 15, 1884 M Oct. 21, 1884
FISH, WALTER CLARK	Manager Lynn Works, General Electric Co., Lynn, Mass.	A June 26, 1891 M Feb. 26, 1896
FITZMAURICE, JAMES S.	Chief Engineer, The Electric Light Branch, 210 George St, Sydney, N. S. W.	A Sept. 20, 1893 M Mar. 21, 1894
FLACK, J. DAY	Consulting Engineer, 1010 Havemeyer Bldg.; residence, 252 West 85th St., New York City.	A Dec. 6, 1887 M May 21, 1895

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Name.	Address.	Date of Membership.
FLEMING, WILFRID H.	70 W. 3d St., Bayonne City, N. J.	A Dec. 6, 1887 M Jan. 3, 1888
FOSTER, HORATIO A.	Electrical Engineer, 13½ Swan St., Buffalo.	A June 8, 1887 M Sept. 6, 1887
FREEMAN, DR. FRANK L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889
FREEDMAN, WILLIAM H.	Tutor in Electrical Engineering, School of Mines, Columbia College; residence, 157 W. 119th St., New York City.	A Mar. 18, 1890 M Dec. 18, 1895
GALE, HORACE B.	Consulting Electrical and Mechanical Engineer, 12 West 31st St., New York City.	A Nov. 15, 1892 M May 16, 1893
GARDANIER, GEORGE W.	Assis't Electrical Engineer Western Union Telegraph Co., 195 Broadway, New York City.	A April 18, 1893 M Jan. 22, 1896
GARRATT, ALLAN V.	Chief Engineer, Lombard Waterwheel Governor Co., 61 Hampshire St., Boston, Mass.	A April 2, 1889 M May 7, 1889
GEYER, DR. WM. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
GHARKY, WILLIAM DAVID	Sup't Underground Cable Construction and Maintenance, Philadelphia Traction Co.: residence, Windsor Hotel, Philadelphia, Pa.	A May 21, 1895 M Feb. 26, 1896
GIFFORD, CLARENCE E.	Electrical Engineer, Supt. Jamestown Electric Light and Power Co., Jamestown, N. Y.	A May 16, 1893 M Feb. 21, 1894
GRAY, DR. ELISHA	Electrician and Inventor, Highland Park, Ill.	A Feb. 16, 1892 M May 17, 1892
GREENE, S. DANA	Assistant General Manager, General Electric Co., Schenectady, N. Y.	A Sept. 20, 1893 M April 18, 1894
GRISCOM, WM. W., *M.A.*	Electrical Engineer, 224 Chestnut St., Philadelphia; residence, Haverford, Pa.	A June 5, 1888 M Mar. 18, 1890
GUTMANN, LUDWIG	Electrical Engineer, 410 La Salle Ave., Chicago, Ill.	A Sept. 14, 1883 M Mar. 21, 1898
HALL, CLAYTON C.	Civil Engineer, 810 Park Ave., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884
HALL, JOHN L.	Manager, Western Union Telegraph Co., 300 Market St., Wilmington, Del.	A Sept. 22, 1891 M Dec. 20, 1893
HAMBLET, JAMES	(*Vice-President.*) Manager Time Service, W. U. Tel. Co., 195 Broadway, P. O. Box 856, New York City; residence, 20 Sidney Place, Brooklyn, N. Y.	A Nov. 1, 1887 M Dec. 6, 1887
HAMILTON, GEO. A.	(*Treasurer.*) Electrician, Western Electric Co., 22 Thames, cor. Greenwich St., New York; residence, 532 Morris Ave, Elizabeth, N. J	A April 15, 1884 M Oct. 21, 1884

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Name.	Address.	Date of Membership.
HAMMER, WILLIAM J.	(*Manager.*) Consulting and Supervising Electrical Engineer, 1305 Havemeyer Building, 26 Cortlandt St., New York City; residence, Elmora, N. J.	A June 8, 1887 M July 12, 1887
HARTWELL, ARTHUR	Electrical Engineer, Westinghouse Electric and Mfg Co.; residence, 6804 McPherson St., Pittsburg, Pa.	A May 15, 1894 M Nov. 20, 1895
HASKINS, CARYL D.	Electrical Engineer, General Electric Co., 620 Atlantic Ave., Boston, Mass.	A Mar. 18, 1890 M June 20, 1894
HASKINS, CHARLES H.	Electrician, 70 Linwood Avenue, Buffalo, N. Y.	A April 15, 1884 M Oct. 21, 1884
HASKINS, CLARK CARYL	City Electric Light Inspector, 582 West Congress St., Chicago, Ill.	A Sept. 20, 1893 M Mar. 21, 1894
HASSON, W. F. C.	(*Vice-President.*) Firm of Hasson & Hunt, Consulting and Supervising Mechanical and Electrical Engineers, 310 Pine St., Telephone 5650, San Francisco, Cal.	A Mar. 18, 1890 M May 15, 1894
HAYES, HAMMOND V.	Electrician, American Bell Telephone Co., 42 Farnsworth St., So. Boston Mass.	A Nov. 12, 1889 M Mar. 18, 1890
HAYES, HARRY E.	Asst. Electrician, American Telegraph and Telephone Co., 153 Cedar St., New York City.	A April 18, 1893 M Dec. 20, 1893
HAYNES, F. T. J.	Divisional Telegraph Engineer, Great Western Railway, Residence, Belmont Villa, Cheddon Road, Taunton, Eng.	A Dec. 6, 1886 M Jan. 3, 1887
HEINRICH, RICHARD O.	Electrical Engineer, Weston Electrical Instrument Co., 114 William St., Newark, N. J.	A Oct. 1, 1889 M Oct. 25, 1892
HENSHAW, FREDERICK V.	Downes & Henshaw, Consulting Electrical and Mechanical Engineers, 86 Weybosset St., Providence, R. I.	A Feb. 5, 1889 M Nov. 20, 1895
HERING, CARL	(*Manager.*) Consulting Electrical Engineer, 927 Chestnut St.; residence 124 E. Mt. Pleasant Ave., Philadelphia, Pa.	A Jan. 3, 1888 M June 5, 1888
HERING, HERMANN S.	Associate in Electrical Engineering, Johns Hopkins University, residence, 1809 Park Ave., Baltimore, Md.	A April 21, 1891 M April 18, 1893
HERRICK, CHARLES H.	Consulting and Constructing Electrical Engineer, 133 Oliver St., Boston; residence, 22 Herrick St., Winchester, Mass.	A April 21, 1891 M Jan. 17, 1893
HERZOG, F. BENEDICT,	*Ph. D.* President, Herzog Teleseme Co., 55 Broadway, New York City	A May 24, 1887 M July 12 1887
HEWITT, CHARLES	(*Manager.*) Assistant Engineer, Philadelphia Traction Co., 920 Spruce St., Philadelphia, Pa.	A Sept. 16, 1890 M May 17, 1892

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Name.	Address.	Date of Membership.
HIBBARD, ANGUS S.	(*Vice-President.*) General Manager, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Nov. 24, 1891 M Feb. 16, 1892
HIGGINS, EDWARD E.	Editor, *Street Railway Journal*, 26 Cortlandt St., New York City.	A June 8, 1887 M July 12, 1887
HIX, E. RANDOLPH	Hix, Hamilton & Co., Electrical Engineers and Contractors, 41 Wall St., New York City.	A Feb. 21, 1894 M Feb. 27, 1895
HOLMES, FRANKLIN S.	Electrical Engineer, 108 Fulton St., New York City; residence 445a Macon St., Brooklyn, N. Y.	A April 21, 1891 M June 20, 1894
HOUSTON, EDWIN J., *Ph.D.* [Life Member.]	(*Past President.*) Prof of Physics, Franklin Inst., Firm of Houston & Kennelly, 1105 Betz Bldg.; residence, 1809 Spring Garden St., Philadelphia, Pa.	A April 15, 1884 M Oct. 21, 1884
HOWELL, JOHN W.	Electrician, 761 High St., Newark, N. J.	A July 12, 1887 M June 5, 1888
HOWELL, WILSON S.	General Electric Lamp Works, Harrison, N.J.: residence, 19 Webster Place, Orange, N. J.	A Sept. 3, 1889 M Mar. 18, 1890
HUNTER, RUDOLPH M.	Expert and Counsellor in Patent Causes, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
HUNTING, FRED S.	Chief Engineer, Fort Wayne Electric Co., 330 West Washington St., Fort Wayne, Ind.	A Nov. 15, 1892 M May 16, 1893
HUTCHINSON, DR. CARY T.	(*Manager.*) Electrical Engineer, 253 Broadway; residence, 56 W. 25th St., New York City.	A Feb. 7, 1890 M Dec. 16, 1890
HYDE, JEROME W.	Ass't Treasurer, The Springfield Steam Power Co., Wason Bldg. Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
INRIG, ALEC GAVAN	Globe Electrical Co., 44 White Post Lane, Victoria Park, London, Eng.	A Jan. 19, 1892 M May 17, 1892
IVES, EDWARD B.	West 139th St. and Grand Boulevard, New York City.	A April 2, 1889 M May 15, 1894
JACKSON, DUGALD C.	Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890
JACKSON, FRANCIS E.	Aylsworth & Jackson, Incandescent Filament Manufacturers, 128 Essex Ave., Orange; residence, 61 South Grove St., East Orange, N. J.	A Jan. 3, 1888 M June 17, 1890
JACKSON, HENRY	Telegraph Supt. and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le-Moors, Lancashire, England.	A Mar. 21, 1894 M Dec. 19, 1894
JACKSON, J. P.	Professor of Electrical Engineering, Penn. State College, State College, Pa.	A Sept. 27, 1892 M Jan. 17, 1894
JANNUS, FRANKLAND	Attorney-at-Law, Solicitor of Patents, 928-30 F. St., N. W. Washington, D. C.	A Nov. 12, 1889 M Mar. 18, 1890

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Name.	Address.	Date of Membership.
JEHL, FRANCIS	Representative, F. Hardtmuth & Co., 60 Liberty St., New York City.	A June 27, 1895 M Jan. 22, 1896
JENKS, W. J.	Patent Department, General Electric Co., 44 Broad Street, Box 3067, New York City.	A June 8, 1887 M Nov. 1, 1887
JOHNSTON, A. LANGSTAFF	Chief Engineer, Richmond Traction Co., 1112 E. Main St., Richmond, Va.	A April 21, 1891 M April 18, 1894
JONES, FRANCIS WILEY [Life Member.]	Assistant Gen'l Manager and Electrician, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 15, 1884 M Oct. 21, 1884
KEITH, DR. NATHANIEL S.	Sandycroft Foundry, E. W. Co., Hawarden, near Chester, Eng.	A June 6, 1893 M Jan. 17, 1894
KIMBALL, DR. ALONZO S.	Professor of Physics, and Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.	A Sept. 3, 1889 M Mar. 20, 1895
KINSMAN, FRANK E.	Electrical Engineer, 66 Broadway, New York City; residence, Plainfield, N. J.	A Sept 27, 1892 M May 16, 1893
KNOWLES, EDWARD R. *E. E., C. E.*	General Manager, Electrical Dep't, Blake & Williams, 362 West Broadway, New York; residence, 36 Cambridge Place, Brooklyn, N. Y.	A June 8, 1887 M July 12, 1887
KNUDSON, A. A.	Electrical Engineer, 688A Greene Ave., Brooklyn, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
LANGE, PHILIP A.	Superintendent Westinghouse Electric and Manufacturing Co., East Pittsburg, Pa.	A Mar. 6, 1888 M June 5, 1888
LANGTON, JOHN	Electrical Engineer, Canada Life Building, Toronto, Ont., and 29 Broadway, New York, N. Y.	A Mar. 6, 1888 M June 5, 1888
LA ROCHE, FRED. A.	Vice-President and General Manager, New York Electric Equipment Co., 572 First Ave., residence, 28 W. 25th St., New York.	A Sept. 19, 1894 M Nov. 20, 1895
LATTIG, J. W.	Electrical Engineer, Supt. of Telegraph and Electrical Apparatus, Lehigh Valley R. R. Co., So. Bethlehem, Pa.; residence, 335 Broad St., West Bethlehem, Pa	A June 8, 1887 M July 12, 1887
LAWSON, A. J.	Electrical Engineer, The County of London and Brush Provincial Elecrtic Lighting Co., Ltd., 49 Queen Victoria St., London, Eng.	A Mar. 18, 1890 M June 17, 1890
LEMP, HERMANN, JR.	Electrician, Thomson Electric Welding Co., Lynn, Mass.	A April 2, 1889 M Feb. 21, 1893
LEONARD, H. WARD	Electrical Engineer, East Orange, N. J.	A July 12, 1887 M Sept. 6, 1887
LEONARD, M. B.	Electrical Engineer, and Supt. of Telegraph, Chesapeake & Ohio R'y. Co., Richmond, Va.	A Nov. 6, 1886 M May 1, 1888

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Name.	Address.	Date of Membership.
LIEB, JOHN W., JR.	Ass't General Manager, Edison Electric Ill. Co.; Residence, 166 West 97th St., New York City.	A Sept. 6, 1887 M Nov. 1, 1887
LIGHTHIPE, JAMES A.	District Engineer, General Electric Co., 15 First St., San Francisco, Cal.	A Feb. 21, 1894 M April 17, 1895
LLOYD, HERBERT	General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Drexel Bldg., Philadelphia, Pa.	A June 20, 1894 M May 21, 1895
LLOYD, ROBERT MCA.	Electrician, 27 Pine St.; residence, 1 West 39th St , New York City.	A Oct. 21, 1890 M Nov. 15, 1893
LOCKWOOD THOMAS D., [Life Member.]	*F. I. Inst.* Electrical Engineer, and Advisory Electrician, P.O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LORRAIN, JAMES GRIEVE	Norfolk House, Norfolk St., London, W. C., England.	A May 16, 1891 M May 15, 1894
LOVEJOY, J. R.	General Manager, Supply Dept., General Electric Co., Schenectady, N. Y.	A April 21, 1891 M Feb. 21, 1894
MACFARLANE, ALEXANDER,	*D. Sc., LL.D.* Professor in Electrical Engineering, Lehigh University, South Bethlehem. Pa.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O.	Consulting Electrical Engineer, 150 Nassau St., Telephone 3985 Cortlandt, New York City.	A April 15. 1884 M Oct. 21, 1884
MANSFIELD, ARTHUR NEWHALL	Assistant Electrician, American Telephone and Telegraph Co., 153 Cedar St., New York City.	A Dec. 20, 1893 M June 20, 1894
MARKS, LOUIS B., *M. M. E.*	Treasurer and Electrician, The Electric Arc Light Co , 73 Watts St.; residence, 51 East 67th St., New York City.	A May 20, 1890 M Jan. 16, 1895
MARKS, WILLIAM DENNIS,	*Ph.B. C. E.* Edison Electric Light Co., Philadelphia, Pa.	A Feb. 7. 1888 M May 1. 1888
MARSHALL, J. T.	Metuchen, N. J.	A Oct. 1, 1889 M Nov. 12, 1889
MARTIN, JULIUS	Electrician, 16 Oak St., Newark, N. J., Master Electrician, Equipment Dept., New York Navy Yard.	A Oct. 21, 1890 M Nov. 20, 1895
MARVIN, HARRY N.	Electrical Engineer and Manager, Marvin Electric Drill Co., Canastota, N. Y.	A April 19. 1892 M Jan. 17. 1893
MAVER, WILLIAM, JR.	Electrical Expert and Consulting Electrical Engineer, 31 Nassau St., New York City; residence, 227 Arlington Ave. Jersey City, N. J.	A July 12, 1887 M April 21, 1891
MAYER, GEORGE M.	Enterprise Block, 5th Floor, 79 Fifth Ave., Chicago, Ill.	A Dec. 16, 1890 M June 20, 1894
MAYNARD, GEO. C.	Electrical Engineer, 800 H. St., N. W., Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
MCCAY, H. KENT	Electrical Engineer and Contractor, 106 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891

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Name.	Address.	Date of Membership.
McCluer, C. E.	Superintendent, First District, So. Bell Telephone and Telegraph Co., P. O. Box 32, Richmond, Va.	A Mar. 21, 1893 M Jan. 17, 1894
McCrossan, J. A.	Manager and Electrician, Citizens' Telephone and Electric Co., Rat Portage, Ont.	A Oct. 18, 1893 M Dec. 18, 1895
Mershon, Ralph D.	Electrical Engineer, Westinghouse Elec. and Mfg. Co. Pittsburg, Pa.	A Mar. 20, 1895 M Jan. 22, 1896
Metcalfe, George R.	136 Liberty Street; residence, 404 West 22d St., New York City.	A April 19, 1892 M Nov. 15, 1892
Millis, John	Captain of Engineers U. S. A., The Lighthouse Board, Washington, D. C.	A July 7, 1884 M Mar. 3, 1885
Mills, Frank P.	Superintendent Cleveland Iron Mining Co., Ishpeming, Mich.	A Jan. 6, 1885 M Mar. 3, 1885
Mix, Edgar W.	Electrician, with Thomson-Houston International Electric Co, 27 Rue de Londres, Paris, France.	A Sept. 3, 1889 M Mar. 20, 1895
Molera, E. J.	Civil Engineer, 606 Clay St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892
Moore, D. McFarlan	Inventor, Moore Electrical Co., 52 Lawrence St., Newark, N. J.	A Dec. 20, 1893 M June 20, 1894
Morrow, John Thomas	Supt. Electrolytic Plant, Boston and Montana Consolidated Copper and Silver Mining Co., Great Falls, Mont.	A Dec. 21, 1892 M April 18, 1894
Neiler, Samuel G.	Ass't Electrical Engineer, Pierce & Richardson, 1409 Manhattan Building, Chicago, Ill.	A April 18, 1894 M Dec. 18, 1895
Nichols, Dr. Edward L.	Professor of Physics, Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
Noll, Augustus	Contracting Electrical Engineer, 8 East 17th St., Telephone, 62, 18th; New York City.	A Sept. 27, 1892 M April 18, 1893
Nunn, Paul N.	Consulting Engineer, San Miguel Cons. Gold Mining Co, Telluride, Colo.	A April 17, 1895 M Feb. 26, 1895
O'Connell, Joseph J.	Telephone Engineer, Chicago Telephone Co., Residence, 76 Eugene St., Chicago, Ill.	A Oct. 17, 1894 M Nov. 20, 1895
Oudin, Maurice	Electrical Engineer, General Electric Co, Schenectady, N. Y.	A June 20, 1894 M Nov. 20, 1895
Paine, F. B. H.	Westinghouse Electric and Mfg. Co, 328 Exchange Building, Boston, Mass.	A Dec. 16, 1890 M Nov. 25, 1891
Paine, Sidney B.	General Electric Co., 180 Summer St., Boston, Mass.	A June 8, 1887 M Nov. 1, 1887
Parks, C. Wellman	1825 Fifth Ave., Troy, N. Y.	A July 12, 1887 M May 1, 1888
Parshall, H. F.	Electrical Engineer, British Thomson-Houston, Ltd., 38 Parliament St., Westminster, London, Eng.	A Sept. 7, 1888 M Mar. 18, 1890

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Name.	Address.	Date of Membership.
PATTISON, FRANK A.	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers, 136 Liberty St., New York City.	A Sept. 22, 1891 M Dec. 16, 1891
PEARSON, F. S.	Engineer, Room 811, 621 Broadway, New York City.	A Oct. 25, 1892 M Feb. 21, 1893
PEROT, L. KNOWLES	Vice-President and Manager, Schuylkill Valley Illuminating Co., Phœnixville, Pa.	A Mar. 15, 1892 M Dec. 18, 1895
PERRINE, FREDERIC A. C., *D. Sc.*	Professor of Electrical Engineering, Leland Stanford, Jr., University, Palo Alto, Cal.	A Sept. 16, 1890 M Dec. 16, 1890
PERRY, NELSON W., *E. M.*,	Electrical Engineer, 6 Park Place, N. Y. City; residence, 18 Sidney Place, Brooklyn, N. Y.	A May 17, 1892 M Mar. 21, 1893
PICKERNELL, F. A.	Chief Engineer, Amer. Tel. & Tel. Co., 153 Cedar St., New York City.	A Feb. 7, 1890 M Mar. 18, 1890
PIERCE, RICHARD H.	Pierce & Richardson, Electrical Engineers, 1409 and 1410 Manhattan Bldg., Chicago; residence, 5434 Monroe Ave., Hyde Park, Ill.	A April 18, 1893 M Dec. 20, 1893
PIKE, CLAYTON W., *B.S.*	Electrical Engineer, Falkenau Engineering Co., 711 Reading Terminal, Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892
PORTER, J. F.	Manager, Alton Electric Street Railroad Co., Alton, Ill.	A Sept. 6, 1887 M Nov. 1, 1887
POWELL, WILLIAM H.	Electrical Engineer, 55 Oak St., Hartford, Ct.	A June 17, 1890 M Mar. 20, 1893
PRATT, ROBERT J.	Greenbush, N. Y.	A July 12, 1887 M Sept. 6, 1887
PUFFER, WM. L.	Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston; residence, West Newton, Mass.	A Dec. 20, 1893 M April 17, 1895
RAE, FRANK B.	Electrical Engineer, 1109 Fort Dearborn Bldg., 134 Monroe St., Chicago, Ill.	A April 15, 1884 M Oct. 25, 1892
REBER, SAMUEL	Lieut. Signal Corps, U. S. Army, Care of Chief Signal Officer U. S. A., Washington, D. C.	A Sept. 20, 1893 M Jan. 22, 1896
RECKENZAUN, FREDERICK,	Electrical Engineer, 44 Pine St., New York City.	A Mar. 6, 1888 M June 5, 1888
REIST, HENRY G.	Designing Engineer, General Electric Co., 5 South Church St., Schenectady, N. Y.	A June 17, 1890 M Dec, 19, 1894
RICE, E. WILBUR, JR.	Technical Director, The General Electric Co., Schenectady, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
RIES, ELIAS E.	Electrical Engineer and Inventor; residenc, 1919 Druid Hill Ave., Baltimore, Md.	A July 12, 1887 M Sept. 6, 1887
RIKER, ANDREW L. [Life Member.]	Electrical Engineer, The Riker Electric Motor Co., 45 York St., Brooklyn; residence, Stamford, Conn.	A Nov. 1, 1887 M Dec. 18, 1895

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Name.	Address.	Date of Membership.
ROBB, RUSSELL	With Stone & Webster, 4 Post Office Square, Boston, Mass.	A Oct. 18, 1893 M May 21, 1895
ROBB, WM. LISPENARD	Professor of Physics, Trinity College, Hartford, Conn.	A Dec. 16, 1891 M Mar. 15, 1892
ROBERTS, E. P.	E. P. Roberts & Co., Electrical and Mechanical Engineers, Brainard Block, Telephone 2656, Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
RODGERS, HOWARD S.	Electrical Engineer, care General Electric Co., 264 W. 4th Street, Cincinnati, O.	A Sept. 27, 1892 M May 16, 1893
ROHRER, ALBERT L.	Electrical Engineer, with General Electric Co., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
ROSS, NORMAN	Assistant Works Engineer, Canadian General Electric Co., Peterboro, Ont.	A Sept 20, 1893 M Nov. 21, 1894
ROSS, ROBERT A.	Electrical Engineer, Royal Electric Co., 94 Queen St., Montreal, P. Q.	A Sept. 27, 1892 M April 18, 1893
ROUQUETTE, WILLIAM F. B.	Proprietor, Rouquette & Co., 47 Dey St., New York City.	A Mar. 21, 1894 M Dec. 19, 1894
RYAN, HARRIS, J.	(*Manager.*) Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M April 17, 1895
SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, [Life Member]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W. England.	A Feb. 7, 1888 M May 1, 1888
SANDS, H. S.	Consulting and Constructing Electrical Engineer, Peabody Building, Wheeling, W. Va.	A Feb. 21, 1893 M Nov. 21, 1894
SARGENT, W. D.	General Manager, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	A April 15, 1884 M Feb. 21, 1894
SCHEFFLER, FRED. A.	Stirling Boiler Co., 126 Liberty Street, New York City; residence, Passaic, N. J.	A May 16, 1893 M Jan. 26, 1896
SCHMID, ALBERT	Superintendent, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A Oct. 21, 1890 M April 17, 1895
SCOTT, CHARLES F.	(*Manager.*) Chief Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893
SHALLENBERGER, O. B.	Consulting Electrician, Westinghouse Electric and Mfg. Co., of Pittsburg; Rochester, Pa.	A Sept. 7, 1888 M Dec. 4, 1888
SHAW, EDWIN C.	Manager, Akron General Electric Co., Akron, O.	A May 17, 1892 M Feb. 27, 1895
SHEA, DANIEL W.	Professor of Physics, Catholic University of America, Washington, D. C.	A Dec. 20, 1893 M June 20, 1894
SHEBLE, FRANKLIN	Sheble & Patton, Ltd., 1026 Filbert St., Philadelphia, Pa.	A Oct. 21, 1890 M Dec. 18, 1895

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Name.	Address.	Date of Membership.
SHELDON, SAMUEL, *A. M., Ph.D.*	Professor of Physics and Electrical Engineering. Polytechnic Institute, 170 State St., Brooklyn, N. Y.	A Dec. 16, 1890 M Oct. 27, 1891
SHEPARD, WM. E.	Steinway Railway Co., Long Island City, N. Y.	A Feb. 7, 1890 M Mar. 18, 1890
SHEPARDSON, GEORGE D.	Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	A April 21, 1891 M Jan. 22, 1896
SINCLAIR, H. A.	Electrical Engineer, The Tucker Electric Co., 950 Bedford Ave., Brooklyn, N. Y.	A June 17, 1890 M Feb. 26, 1896
SLATER, HENRY B.	Vice-President and Manager, The Canon City Electric Light and Power Co., Canon City, Col.	A April 15, 1884 M Dec. 9, 1884
SMITH, FRANK STUART	Supt. Lamp Factory. Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	A Sept. 27, 1892 M April 18, 1893
SMITH, JESSE M.	Expert in Patent Causes, Consulting Electrical and Mechanical Engineer, 36 Moffat Block, Detroit, Mich.	A April 15, 1884 M June 26, 1891
SMITH, T. CARPENTER	Mechanical and Electrical Engineer, 212 Drexel Building, Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891
SPAULDING, HOLLON C.	Electrical Engineer, 93 Liberty St., New York City.	A April 21, 1891 M June 20, 1894
SPERRY, ELMER A.	Electrical Engineer, Sperry Electric Railway Co., Mason and Belden Sts., Cleveland, O.	A April 19, 1892 M Feb. 21, 1893
STANDFORD, WILLIAM	Asst. Supt. Telegraphs. Colonial Govt., Cape Town, Cape of Good Hope, Africa.	A Oct. 4, 1887 M Dec. 6, 1887
STEARNS, CHARLES K. *E.E.*	Ass't Supervising. Electrical Engineer, N. Y. N. H. and H. R. R. Kneeland St., Station, Boston, Mass.	A Aug. 6, 1889 M May 16, 1893
STEARNS, JOEL W., JR.	Treasurer. Mountain Electric Co., Box 1545, Denver, Col.	A June 20, 1894 M Nov. 20, 1895
STEBBINS, THEODORE	Superintendent Railway Construction, General Electric Co., Schenectady, N. Y.	A July 9, 1889 M June 17, 1890
STEINMETZ, CHARLES P.	Electrician, General Electric Co., Schenectady, N. Y.	A Mar. 18, 1890 M April 21, 1891
STEPHENS, GEORGE	General Supt., Canadian General Electric Co., Ltd., Peterboro, Ont.	A June 20, 1894 M Dec. 18, 1895
STIERINGER, LUTHER	Electrical Expert, Morris Building, 68 Broad St., New York City.	A June 8, 1887 M Nov. 1, 1887
STILLWELL, LEWIS B.	Electrical Engineer and Assistant Manager, Westinghouse Electric and M'f'g Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
TAINTOR, GILES	Division Sup't. Western Division New England Telephone and Telegraph Co., Springfield, Mass.	A June 26, 1891 M Dec. 16, 1891

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Name.	Address.	Date of Membership.
TALTAVALL, THOS. R.	Editor, *Electric Age*, World Building, New York City.	A Jan. 20, 1891 M Oct. 27, 1891
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A April 5, 1887 M May 17, 1887
THOMAS, BENJAMIN F., *Ph. D.*	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, PROF. ELIHU	(*Past President*). Electrician, General Electric, and Thomson Electric Welding Companies, Lynn, Mass.	A April 15, 1884 M April 21, 1891
THOMPSON, EDWARD P.	Consulting Electrician and Patent Attorney in Electrical Cases, 5 Beekman St., New York City.	A April 15, 1884 M Dec. 3, 1889
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 27 Rue de Londres, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TISCHENDOERFER, F. W.	Electrical Engineer, Schückert & Co., Nuremberg, Germany.	A April 19, 1892 M Nov. 21, 1894
TRAFFORD, EDWARD W.	Electrical Engineer, Richmond Railway and Electric Co., Foot of 7th St., Richmond, Va.	A Feb. 21, 1894 M Dec. 19, 1894
TURNER, WILLIAM S.	President, Woodbridge & Turner Engineering Co., 47 Times Building, New York City.	A Dec. 7, 1886 M Oct. 2, 1888
UEBELACKER, CHAS. F.	Electrical Engineer, Consolidated Traction Co., 30 North 11th St., Newark, N. J.	A Feb. 7, 1890 M Nov. 15, 1893
UHLENHAUT, FRITZ, JR.	Philadelphia Traction Co., 4101 Haverford St., Philadelphia, Pa.	A May 7, 1889 M Dec. 19, 1894
UPTON, FRANCIS R	Sales Manager National Tube Works Co, McKeesport, Pa.; residence, 107 Day St., Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VAIL, J. H	President and Chief Engineer, Electrical and Mechanical Engineering Co., 39 Cortlandt St., New York City.	A June 8, 1887 M Nov. 1, 1887
VANSIZE, WILLIAM B.	(*Manager*) Solicitor of Patents and Expert, 253 Broadway, New York City.	A April 15, 1884 M Oct, 21, 1884
VAN TRUMP, C. REGINALD	Engineer and Manager, Wilmington City Electric Co, Wilmington, Del.	A Feb. 5, 1886 M Feb. 21, 1894
WADDELL, MONTGOMERY	Consulting Engineer, 29 Broadway, New York City.	A Feb. 7, 1888 M May 1, 1888
WAIT, HENRY H.	Assistant Electrical Engineer, Western Electric Co., 4919 Madison Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WALDO, DR. LEONARD	Electrical Engineer, Secretary, The Waldo Foundry, 57 Coleman St., Bridgeport, Conn.	A June 5, 1888 M Dec. 4, 1888

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Name.	Address.	Date of Membership.
WALKER, SYDNEY F.	Electrical Engineer, 195 Severn Road, Cardiff, Wales.	A June 2, 1885 M May 17, 1887
WARING, JOHN	Waring Electric Co., Ovid, N. Y.	A Dec. 16, 1890 M April 17, 1895
WARNER, ERNEST P.	Electrical Engineer, Western Electric Co., 227 So. Clinton St., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WATERMAN, F. N.	Electrical Engineer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A Feb. 21, 1893 M June 20, 1894
WEAVER, W. D.	(*Manager.*) 7 West 26th St., New York City.	A May 17, 1887 M May 17, 1887
WEBB, HERBERT LAWS	18 Cortlandt St.; residence, 126 East 19th St., New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEEKS, EDWIN R.	Rooms 301 to 303, National Bank of Kansas City Building, Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Electrical Engineer, Room 33, Equitable Building, Boston, Mass.	A Oct. 21, 1890 M Nov. 24, 1891
WESTON, EDWARD	(*Past President.*) Vice-President. Weston Electrical Instrument Co, 120 William St., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884
WETZLER, JOSEPH	Editor *The Electrical Engineer*, 203 Broadway, New York City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	82 Bond St., London, Eng,	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER SKAATS, *Sc.D.* [Life Member.]	Pres. Crocker-Wheeler Electric Co., 39 Cortlandt St., and Ampere, N. J.; residence, 4 West 33d St., New York City.	A June 2, 1885 M Sept. 1, 1885
WHITE-FRASER, GEO.	Care of John Stark & Co., 28 Toronto St., Toronto, Ont.	A Sept. 22, 1891 M Dec. 18, 1895
WIENER, ALFRED E.	Electrical and Mechanical Engineer; residence, 208 Liberty St., Schenectady, N. Y.	A May 16, 1893 M May 15, 1894
WILCOX, NORMAN T.	Manager and Electrican, Seneca Light and Power Co., Seneca Falls, N. Y.	A May 21, 1895 M Jan. 22, 1896
WILKES, GILBERT	Consulting Electrical Engineer, 816 Chamber of Commerce Bldg., Detroit, Mich.	A Jan. 7, 1890 M Mar. 18, 1890
WILLYOUNG, ELMER G.	E. G. Willyoung & Co., Scientific Instruments and Apparatus, 938 Market St., Philadelphia.	A Nov. 24, 1891 M Dec. 20, 1893
WILSON, CHARLES H.	Monadnock Building, Chicago Ill.	A Nov. 24, 1891 M Feb. 16, 1892
WILSON, FREMONT	Electrician, 66 Maiden Lane, (Telephone, 1651 Cortlandt) and 2153 Seventh Ave., New York City.	A Mar. 6, 1888 M June 5, 1888
WILSON, HARRY C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892

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Name.	Address.	Date of Membership.
WINCHESTER, A. E.	Consulting Engineer and Designer of Electric Systems, South Norwalk, Conn.	A June 8, 1887 M Nov. 1, 1887
WINSLOW, GEORGE HERBERT	Consulting Electrical Engineer, 700 Lewis Block, 6th Ave., and Smithfield St., Pittsburg, Pa.	A April 17, 1895 M Feb. 26, 1896
WIRT, CHARLES	Consulting Engineer, 5104 Newhall St., Germantown, Pa.	A Sept. 8, 1888 M June 20, 1894
WOLCOTT, TOWNSEND	Electrician, 1002 Bennett Building, New York City.	A Mar. 6, 1888 M Dec. 16, 1890
WOLVERTON, B. C.	Electrician, N. Y. & Pa. Telephone and Telegraph Co., Elmira, N. Y.	A Mar. 18, 1890 M Feb. 21, 1895
WOODBRIDGE, J. L.	Secretary and Treasurer, Woodbridge & Turner Engineering Co., 47 Times Building, New York City.	A June 8, 1887 M Nov. 1, 1887
WRIGHT, PETER	Inspector of Electrical Works, United Gas Improvement Co., 807 Drexel Bldg, Philadelphia, Pa.	A May 16, 1889 M Jan. 16, 1895
WURTS, ALEXANDER JAY	Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
YOUNG, C. GRIFFITH	Electrical Engineer, White-Crosby Co., 706 Equitable Building., Baltimore, Md.	A Jan. 3, 1889 M April 21, 1891

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ASSOCIATE MEMBERS.

Name.	Address.	Date of Election.
ADAMS, COMFORT A., JR.	Instructor in Electrical Engineering, Harvard University, 13 Farrar St., Cambridge, Mass.	Jan. 17, 1894
ADAMSON, DANIEL	Manager Joseph Adamson & Co., Hyde, Cheshire, England.	Feb. 26, 1896
AGNEW, CORNELIUS R.	Electrical Engineer, 150 Nassau St., 23 West 39th St., New York City.	Mar. 21, 1894
ALBANESE, G. SACCO	Electrical Expert, Compagnie Francaise Thomson-Houston, 27 Rue de Londres, Paris, France.	Sept. 20, 1893
ALBERT, HENRY	Electrical Engineer, care Citizens Gas and Electric Co., Jacksonville, Fla.	Feb. 21, 1893
ALDEN, JAMES S.	Assistant Manager, with L. H. Alden, 486 River Drive, Passaic, N. J.	May 19, 1891
ALDRICH, WILLIAM S.	Professor of Mechanical Engineering and Director Mechanical Arts, West Virginia University, P. O. Box 256, Morgantown, W. Va.	Mar. 15, 1892
ALEXANDER, HARRY	Electrical Engineer, General Manager and Vice Prest. Alexander-Chamberlain Electric Co., 126 Liberty, and 348 W. 145th St., New York City.	April 21, 1891
ALEXANDER, P. H.	Manager, Lighting Dept., Electric Selector and Signal Co., 45 Broadway, New York City.	Dec. 16, 1890
ANDERSON, HENRY S.	General Manager and Electrician, United Electric Light Co., Springfield, Mass.	Jan. 16, 1895
ANDERSON, W. E.	Professor of Physics and Electrical Engineering, Pacific Building, Washington, D C.	Sept. 20, 1893
ANDREWS, WILLIAM, C.	Electrical Engineer, 162 Hicks St., Brooklyn, N. Y.	May 21, 1895
ANDREWS, WM. S.	General Electric Co., Schenectady, N. Y.	Mar. 5, 1889
ANSON, FRANKLIN ROBERT	Receiver, Salem Consolidated Street Railway Co., Salem, Ore.	Feb. 27, 1895
ANTHONY, WATSON G.	Electrician, 32½ Webster St., Newark, N. J.	Feb. 24, 1891
ARCHBOLD, WM. K.	Westinghouse Electric and Mfg. Co. 328 Exchange Bldg., Boston, Mass.	June 20, 1894
ARCHER, GEO. F.	31 Burling Slip, New York City.	Nov. 21, 1894
ARMSTRONG, CHAS. G.	Electrical Expert, 1400 Auditorium Tower, Chicago, Ill.	Sept. 27, 1892
ARNOLD, CRAIG R.	Electrician and Treasurer, Arnold Electric Co., Chester and Sharon Hill, Pa.	Nov. 15, 1892
ASHLEY, FRANK M.	Master Mechanic, Ashley Engineering Works, Hawthorne, N. J., 136 Liberty St., N. Y.	Nov. 21, 1894
ATWOOD, GEORGE F.	Mechanic and Lawrence Sts., Newark, N. J.	Sept. 16, 1890

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Name.	Address.	Date of Election.
AUSTIN, SYDNEY B.	55 Franklin St.; residence, 130 West 83rd Street, New York.	Sept. 25, 1895.
AUERBACHER, LOUIS J.	Secretary and General Manager, Automatic Electrical Specialty Co., Newark. N. J.	Sept. 20, 1893.
BABCOCK, CLIFFORD D.	[Address unknown]	Feb. 21, 1894.
BADEAU, ISAAC F.	Ass't to the Engineer, Met. Telephone and Telegraph Co.; residence, 215 W. 122d St., New York City.	Feb. 26, 1896
BADT, LIEUT. FRANCIS B.	Electrical Engineer, Siemens & Halske Electric Co. of America, 1215 Monadnock Block and 6506 Lafayette Ave., (Englewood), Chicago, Ill.	April 19, 1892
BALDWIN, JAS. C. T.	Superintendent Chicago Telephone Co., 203 Washington St.; residence, 382 Ontario Street, Chicago, Ill.	April 17, 1895
BALL, WM. D.	Consulting Electrical Engineer, W. D. Ball & Co , 1625 Monadnock Block, Chicago, Ill.	Nov. 20, 1895
BANCROFT, CHAS. F.	Electrical Engineer, Lowell and Suburban Street Railway, Lowell, Mass.	Dec. 18, 1895
BARBOUR, FRED FISKE	Manager, Power and Mining Department, Pacific District, General Electric Co., 15 First St., San Francisco, Cal., and 1758 10th Ave., Oakland, Cal.	May 16, 1893
BARNARD, JOHN H.	Vice-President and General Manager, Wilmington Street Railway Co., Wilmington, N. C.	June 26, 1891
BARNES, EDWARD A.	Electrical Expert, Fort Wayne Electric Co., Fort Wayne, Ind.	Sept. 20, 1893.
BARSTOW, WILLIAM S.	General Supt., Edison Electric Illuminating Co., 360 Pearl St., Brooklyn, N. Y.	Feb. 21, 1894
BARTH-BARTOSHEVITCH, A.	Mechanical and Electrical Engineer, [Address unknown.]	May 16, 1893
BARTLETT, EDWARD E.	Member Firm Bartlett & Co., 23 Rose St., New York City.	June 6, 1893
BARTON, ENOS M.	President Western Electric Co., 227 South Clinton St., Chicago, Ill.	July 12, 1887
BATES, FREDERICK C.	Electrical Engineer, Union Elektricitäts Gesellschaft, Berlin, Germany.	Jan. 20, 1891
BAUER, W. F.	Electrician, Reisterstown, Md.	April 15, 1890
BEAMES, CLARE F.	General Electric Co., Monadnock Block, Chicago, Ill.	May 21, 1895
BEATTIE, JOHN, JR.	Manager and Superintendent, The Beattie Battery, Zinc and Electric Co., Fall River, Mass.	Sept. 6, 1887
BEDELL, DR. FREDERICK,	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	April 21, 1891
BENNETT, EDWIN H., JR.	Electrician and Engineer, Diehl & Co., Elizabethport, N. J., and 17 E. 33d St., Bayonne, N. J.	June 20, 1894
BENNETT. JOHN C.	Electrician General Electric Co., Box 3067, 44 Broad St., New York City.	Mar. 18, 1890

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Name.	Address.	Date of Election.
BENTLEY, MERTON H.	Chicago Telephone Co.; residence, 221 Scoville Ave., Oak Park, Ill.	Oct. 18, 1893
BERG, ERNST JULIUS	Engineer, General Electric Co.; residence, 53 Washington Ave., Schenectady, N. Y.	Sept. 19, 1894
BERG, ESKIL	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Nov. 20, 1895
BERGHOLTZ, HERMAN	Secretary and Treasurer, Ithaca Street Railway Co., Ithaca, N. Y.	April 2, 1889
BERLINER, EMILE	Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C.	April 15, 1884
BERRESFORD, ARTHUR W., *B. S., M. E.*	Electrician, Brooklyn City R. R. Co., 197 Van Buren St., Brooklyn, N. Y.	May 15, 1894
BEST, A. T.	Electrical Engineer, St. Augustine, Florida.	April 19, 1894
BETHELL, U. N.	General Manager, The Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., N. Y. City.	Jan. 17, 1894
BIJUR, JOSEPH, *A. B., E. E.* [Life Member.]	Consulting Electrical Engineer, 34 Nassau St., residence, 172 West 75th St., New York City.	May 15, 1894
BLACK, CHAS. N.	Brush Electric Co., Belden St., Cleveland, O.	April 19, 1890
BLAKE, HENRY W.	Editor, *Street Railway Journal*, 26 Cortlandt St., New York City.	Nov. 13, 1888
BLAKE, THEODORE W.	American Telephone and Telegraph Co., 18 Cortlandt Street, New York, N. Y.	Sept. 20, 1893
BLANCHARD, CHARLES M.	Winterburn, Pa.	Sept. 19, 1894
BLAXTER, GEO. H.	Vice-President and General Manager, Allegheny County Light Co., Westinghouse Building, Pittsburg, Pa.	Sept. 25, 1895
BLISS, DONALD M.	Electrician, Holtzer-Cabot Electric Co., 1 Davis Court, Washington St., Brookline, Mass.	Feb. 7, 1890
BLISS, GEORGE S.	Electrical Engineer, Central District and Printing Telegraph Co., Telephone Bldg., Pittsburg, Pa.	June 20, 1894
BLISS, WM. J. A.	820 Connecticut Ave., Washington, D. C.	Jan. 20, 1891
BLISS, WILLIAM L., *B. S., M. M. E.*	Electrical Engineer, Consolidated Gas Co., 4 Irving Place, New York City; residence, 24 Irving Place, Brooklyn, N. Y.	Mar. 21, 1894
BLIZARD, CHARLES	Sales Agent, Electric Storage Battery Co., 66 Broadway; residence, Passaic, N. J.	Nov. 21, 1894
BLOOD, W. HENRY JR.	The Franklin Electric Co., 535 Delaware St., Kansas City, Mo.	April 2, 1889

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Name.	Address.	Date of Election.
BOARDMAN, HARRY B.	Wisconsin Telephone Co., 1530 Grand Ave., Milwaukee, Wis.	Sept. 20, 1893
BOGART, A. LIVINGSTON	Electrical and Patent Expert, 22 Union Square, New York City.	July 10, 1888
BOGGS, LEMUEL STEARNS	Lafayette, Ind.	Sept. 20, 1893
BOGUE, CHARLES J.	Manufacturer and Dealer in Electrical Supplies, 206 Centre St., N.Y. City.	Dec. 3, 1889
BOHM, LUDWIG K., *Ph.D.*,	Consulting Electrical and Chemical Expert, 117 Nassau St., N. Y. City.	Nov. 15, 1892
BOILEAU, WILLIAM E.	Superintendent and Electrician, Brush Electric Light & Power Co., Columbus, Ga.	Sept. 19, 1894
BOUGHAN, EDWARD L.	20 Roslyn Place, Chicago, Ill.	Dec. 21, 1892
BOYER, ELMER E.	Electrical Engineer, The General Electric Co., Lynn, Mass.	Sept. 25, 1895
BOYLES, THOMAS D.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	Mar. 20, 1895
BRACKETT, PROF. CYRUS F.	Princeton, N. J.	April 15, 1889
BRADDELL, ALFRED E.	Electrical Inspector, Underwriters' Association, Middle Department, 316 Walnut St., Philadelphia, Pa.	Sept. 1, 1890
BRADY, E. D. A.	Consulting and Constructing Engineer, 95 Bank St., Lock P. O. Box 132, Waterbury, Conn.	Sept. 19, 1894
BRADY, FRANK W., *M. E.*	Professor of Engineering and Physics, New Mexico.: College of Agriculture and Mechanic Arts, Mesilla Park, N. M.	June 20, 1894
BRADY, PAUL T.	Manager, Central N. Y. Agency, Westinghouse Electric and Mfg. Co., Syracuse, N. Y.	July 12, 1887
BRAGG, CHARLES A.	Manager Phila. Agency, Westinghouse Electric and Mfg. Co., 302 Girard Building, Philadelphia, Pa.	Sept. 20, 1893
BREITHAUPT, E. CARL	Electrical Engineer, Berlin, Ont.	June 6, 1893
BRIXEY, W. R.	Proprietor and Manufacturer, Day's Kerite Wire and Cables, 203 Broadway, New York City.	Sept. 20, 1893
BROICH, JOSEPH	Superintendent and Electrician, with F. Pearce, New York City; residence, 448 8th Ave., Brooklyn, N. Y.	Jan. 17, 1894
BROPHY, WILLIAM	Electrician to the Wire Department, 12 Old Court House, Boston; residence, 17 Egleston St., Jamaica Plain, Mass.	Mar. 5, 1889
BROWN, CHAS. L.	Student at Cornell University.; residence. 6422 Drexel Ave., Chicago, Ill.	Nov. 20, 1895
BRYANT, WALDO C.	Manager and Treasurer, The Bryant Electric Co., Bridgeport, Conn.	May 16, 1893
BUBERT, J. F.	Supervising and Contracting Electrical Engineer, 402 Exchange Bldg., (Telephone 1379) Boston, Mass.	June 7, 1892
BUCK, HAROLD W.	12 N. Church St., Schenectady, N. Y.	Jan. 16, 1895

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Name.	Address.	Date of Election.
BUCKINGHAM, CHAS. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	April 15, 1884
BUNCE, THEODORE D.	The Storage Battery Supply Co., 239 E. 27tn St., New York City.	May 20, 1890
BURKE, JAMES	Firm of Herrick & Burke, 203 Broadway, New York City.	May 16, 1893
BURNETT, DOUGLASS, *B.S.*	Edison Illuminating Co , Inspection Dept., 55 Duane St., New York City; residence, 42 Livingston St., Brooklyn, N. Y.	Feb. 21, 1893
BURT, BYRON T.	Manager and Sec'y. and Treas. Charleston Light and Power Co., Charleston, S. C.	Sept. 25, 1895
BURTON, GEO. D.	Electrician and President, Electrical Forging Co., 194 Washington St., Boston, Mass.	April 21, 1891
BURTON, PAUL G.	Constructing Electrician, Western Electric Co.; residence, 45 W. 127 St., New York City.	Nov. 20, 1895
BURTON, WILLIAM C.	With White-Crosby Co., Equitable Bldg. Baltimore, Md.	Sept. 20, 1893
BUTLER, WILLIAM C.	President, The Puget Sound Reduction Co., Everett, Washington.	Mar. 21, 1893
BUYS, ALBERT	Electrical Engineer, The Rahway Electric Light and Power Co., Rahway, N. J.	Feb. 7, 1890
CABOT, FRANCIS ELLIOTT	Supt. of Inspection and Electrician, Boston Board of Fire Underwriters, 55 Kilby Street; residence, East Milton, Mass.	April 17, 1895
CABOT, JOHN ALFRED	City Electrician, 115 W. 8th St., Cincinnati, O.	May 16, 1893
CALDWELL, EDWARD	*Street Railway Journal*, Havemeyer Bldg., New York City.	Jan. 20, 1891
CALDWELL, FRANCIS C.	Assistant Professor of Electrical Engineering, Ohio State University, Columbus, O.	June 20, 1894
CANFIELD, MILTON C.	Electrical Engineer, 18 Clinton St., Cleveland, O.	Feb. 21, 1893
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St. New York City.	May 21, 1895
CAPUCCIO, MARIO	Raimondo & Capuccio, Consulting Engineers and Patent Agents, Piazza Statuto 15, Turin, Italy.	Dec. 20, 1893
CARHART, HENRY S.	Prof. of Physics, University of Michigan, Ann Arbor, Mich.	Sept. 25, 1895
CARICHOFF, E. R.	Electrical Engineer, Sprague Electric Elevator Co., Bloomfield, N. J.	Mar. 21, 1894
CARSON, DAVID T.	Secy. and Gen. Supt., The Southern Bell Telephone and Telegraph Co., 26 Cortlandt St., New York City.	Dec. 21, 1892

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Name.	Address.	Date of Election.
CARTWRIGHT, FRED'K G.	Electrical Engineer and Agent, Fort Wayne Electric Co., 41 and 43 Stevenson St., San Francisco, Cal.	Sept. 22, 1891
CARTY, J. J.	(*Manager*) Engineer, Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., New York City.	April 15, 1890
CASE, WILLARD E.	196 Genesee St., Auburn, N. Y.	Feb. 7, 1888
CASPER, LOUIS	Electricial Engineer and Contractor, 307 New Ridge Bldg., Kansas City, Mo.	April 21, 1891
CHADBOURNE, HENRY R., JR.	Electrical Engineer, 130 Bedford St., Boston, Mass.	May 15, 1894
CHAMBERLAIN, F. H.	Electrician, Metropolitan R. R. Co., 2411 P St., N. W. Washington, D. C.	June 17, 1890
CHENEY, FREDERICK A.	Maple Avenue, Elmira, N. Y.	Oct. 1, 1889
CHERMONT, ANTONIO LEITE	Engineer, Firm of Chermont, Silva and Miranda, Box 252, Para, U. S. Brazil.	Mar. 18, 1890
CHESNEY, C. C.	Electrician, Stanley Laboratory, Pittsfield, Mass.	June 20, 1894
CHILDS, SUMNER W.	The Degnon Construction Co., Foellinger Block, Fort Wayne, Ind.	May 15, 1894
CHILDS, WALTER H.	Brattleboro, Vt.	Sept. 6, 1887
CHINNOCK, C. E.	137 Sixth Ave., Brooklyn, N. Y.	April 15, 1884
CHISM, GEORGE F.	Chief Engineer, Power Plant Dept. with Le Grand Brown, 90 Exchange Place Bldg., Rochester, N. Y.	Mar. 21, 1893
CHUBBUCK, H. EUGENE	Vice-President, The Pueblo Electric Street Railway Co., Pueblo, Col.	Dec. 4, 1888
CLAFLIN, ADAMS D.	Commonwealth Ave. Street Railway Co., 53 State St., Boston; residence, Newton Centre, Mass.	June 7, 1892
CLARK, LEROY, JR.	Electrician, Safety Insulated Wire and Cable Co., 229 West 28th St., residence, 350 West 30th St., New York City.	May 15, 1894
CLEMENT, LEWIS M.	1013 Central Ave., Oakland, Cal.	April 21, 1891
CLEVELAND, WM. B.	Cleveland, O.	April 15, 1884
CLOUGH, ALBERT L.	Box 114, Manchester, N. H.	Feb. 21, 1894
COFFIN, CHAS. A.	General Electric Co., 620 Atlantic Ave., Boston, Mass.	Dec. 6, 1887
COGSWELL, A. R.	Electrician and Superintendent, Halifax Illuminating and Motor Co., Ltd., 34 Bishop St., Halifax, N. S.	April 21, 1891
COHO, HERBERT B.	H. B. Coho & Co., Electrical Engineers, 203 Broadway, New York City.	Mar. 21, 1894
COLES, EDMUND P.	Special Tester, General Electric Co., Schenectady, N. Y.; residence 240 Union St.	Oct. 23, 1895

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Name.	Address.	Date of Election.
COLGATE, GEO. L.	Electrical Engineer, 136 Liberty St., New York City.	June 17, 1890
COLLES, GEORGE W. JR.	Constructing Engineer, The Viscol Co., 118 Charles St., Boston, Mass.	Oct. 23, 1895
COLLETT, SAMUEL D.	Engineer Construction Dep't Met. Telephone and Tel. Co., 18 Cortlandt St., New York City; residence, 15 Cranberry St, Brooklyn, N. Y.	Feb. 26, 1896
COLLEY, BENJAMIN W.	First Ass't. Superintendent, The Commercial Cable Co., Hazel Hill, N. S..	Oct. 21, 1890
COLVILLE, FRANK C.	Electrician and Inventor, 1503 Seventh Ave., Oakland, Cal.	May 19, 1891
COMPTON, ALFRED G.	Professor of Applied Mathematics, College of the City of New York, 17 Lexington Ave., New York City.	Nov. 1, 1887
COOLIDGE, CHARLES A.	Electrical Engineer, Superintendent, Northern Improvement Co., 591 Hood St., Portland, Ore.	April 19, 1892
COREY, FRED BRAINARD	Consulting Engineer, Room 33, 150 Devonshire St., Boston, Mass.	Dec. 20, 1893
CORNELL, JOHN B.	Supt. of Construction, with Chas. L. Cornell, Hamilton, O.	Sept. 25, 1895
CORSON, WILLIAM R. C.	Electrical Engineer, The Eddy Electric Mfg. Co., Windsor, Conn.	Jan. 17, 1893
CORY, CLARENCE L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892
COSTER, MAURICE	Engineer, Westinghouse Elec. and Mfg. Co., N. Y. Life Bldg., Chicago, Ill.	Sept. 25, 1895
COX, EDMUND V.	Student in Electrical Engineering, Columbia College; residence, 50 East 31st St., New York City.	Jan. 16, 1895
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 227 South Clinton St.; residence, 4438 Ellis Ave. Chicago, Ill.	Sept. 27, 1892
CRANE, W. F. D.	Manager Electrical Department H. W. Johns Manufacturing Co., 87 Maiden Lane, New York City; residence, 24 Halstead Pl., East Orange, N. J.	Feb. 7, 1888
CRAWFORD, DAVID FRANCIS	Ass't to Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Sept. 25, 1895
CRAWFORD, L. G.	Sup't, Repair Dep't General Electric Co., Chicago, Ill.	Oct. 23, 1895
CREAGHEAD, THOMAS J.	President and General Manager, Creaghead Engineering Co., 296 Plum St., Cincinnati, O.	Sept. 20, 1893
CREHORE, ALBERT C., *Ph.D.*	Assistant Professor of Physics, Dartmouth College, Hanover, N. H.	Dec. 21, 1892
CREWS, J. W.	Manager, Southern Bell Telephone and Telegraph Co., Telephone Exchange, Norfolk, Va.	Sept. 19, 1894

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Name.	Address.	Date of Election.
CRIGGAL, JOHN E.	Electrician, 138 Bloomfield Ave., Newark, N. J.	June 20, 1894
CROSBY, OSCAR T.	White-Crosby Co., 29 Broadway, New York City.	Mar. 18, 1890
CROXTON, A. L.	Electrical Engineer, Standard Electric Co., 7118 Drexel Ave., Chicago, Ill.	June 20, 1894
CUMNER, ARTHUR B.	69 Broad St., Boston, Mass.	Feb. 27, 1895
CUNNINGHAM, E. R.	Sup't Fort Dodge Light and Power Co., Fort Dodge, Iowa.	Jan. 22, 1896
CUNTZ, JOHANNES H.	Assistant to President Henry Morton, Stevens Institute of Technology, 325 Hudson St , Hoboken, N. J.	Mar. 5, 1889
CURTIS, CHAS. G.	President, Curtis Electric Mfg. Co., Box 412, New York City,	April 15, 1884
CUSHING, F. W.	Electrical Engineer, 1106 The Rookery, Chicago, Ill.	Nov. 24, 1891
CUSHING, HARRY COOKE, JR.	Electrical Inspector, Boston Board of Fire Underwriters, 55 Kilby St.; residence, 259 Beacon St., Boston, Mass.	Sept. 19, 1894
DACUNHA, MANOEL IGNACIO	Manager of the Electrical Section, Emprera Industrial Gram-Para, Para, U. S. of Brazil.	May 16, 1893
DAME, FRANK L.	General Sup't, Tacoma Railway and Motor Co., Tacoma, Wash.	June 26, 1891
DANA, R. K.	Agent, Washburn and Moen Mfg. Co., 16 Cliff St., New York City.	April 15, 1884
DANIELSON, ERNST	Consulting Electrician, 16 Scheele Gatan, Stockholm, Sweden.	June 27, 1895
DAVENPORT, C. G.	Expert and Agent, General Electric Co., 44 Broad St., New York City.	Nov. 21, 1894
DAVENPORT, GEORGE W.	61 Ames Bldg., Boston, Mass.	June 4, 1889
DAVIDSON, EDW. C.	Patent Lawyer, Room 179 Times Bldg., New York City.	Feb 7, 1890
DAVIS, DELAMORE L.	Superintendent, Salem Electric Light and Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
DAVIS, JOSEPH P.	Engineer, American Bell Telephone Co., 113 W. 38th St., New York City.	April 15, 1884
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 20, 1895
DAWSON, PHILIP	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, Eng.	Sept. 25, 1895
DECKER, EDWARD P.	Electrical Engineer, Met. Telephone and Telegraph Co., 18 Cortlandt St., New York City; residence, Van Pelt Manor, N. Y.	Feb. 26, 1895
DEGEN, LEWIS	Constructing Engineer, Gen'l Electric Co., Rio de Janeiro, Brazil.	Sept. 25, 1895
DEKHOTINSKY, CAPT. ACHILLES,	Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, American Bell Telephone Co., 42 Farnsworth St , Boston, Mass.	Oct. 27, 1891

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Name.	Address.	Date of Election.
DELANCEY, DARRAGH	Manager of Kodak Park Works, Eastman Kodak Co., Rochester, N. Y.	Sept. 19, 1894
DENISON, SYLVESTER P.	143 Centre St., New York City; residence, Belleville, N. J.	Jan. 16, 1895
DENTON, JAMES E.	Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J.	July 12, 1887
DESMOND, JERE. A.	Electrical Engineer, Boston Electric Light Co., Ames Bldg., Boston, Mass	Jan. 19, 1892
DEWAR, JOHN THOMAS	Electrical Expert, Western Electric Co.; residence, 33 Rue Bouewijns, Antwerp, Belgium.	May 21, 1895
DEY, HARRY E.	Pres't and Gen'l Mgr. Dey-Griswold Co., 108 Fulton St., New York City, residence, 342 Tenth St., Brooklyn, N. Y.	Dec. 19, 1894
DICKERSON, E. N.	Attorney-at-Law, 64 E. 34th St., New York City.	April 15, 1884
DOBBIE, ROBERT S.	Electrical Engineer, 2 South Parade, Westmoreland Road, Newcastle-on-Tyne, Eng.	Feb. 5, 1889
DOMMERQUE, FRANZ J.	Chief Draughtsman, Chicago Telephone Co.; residence, 496 N. Robey St., Chicago, Ill.	Oct. 17, 1894
DOOLITTLE, CLARENCE E.	Manager and Electrician, Roaring Fork Electric Light and Power Co., Aspen, Colo.	May 15, 1894
DOOLITTLE, THOMAS B.	Engineering Department, American Bell Telephone Co., 125 Milk St., Boston, Mass.	May 16, 1893
DOREMUS, CHARLES A.	*M.D. Ph.D.* 59 W. 51st St., New York City.	July 7, 1884
DORR, FRANK H.	Electrical Engineer, General Electric Co., Monadnock Building, Chicago, Ill.	May 15, 1894
DRESSLER, CHARLES E.	17 Lexington Ave., New York City.	Dec 16, 1890
DRYSDALE, WILLIAM A.	Consulting Electrical Engineer, Hale Building, Philadelphia, Pa.	Sept. 19, 1894
DU BOIS, JULIAN	Chief Electrician, Mohawk Division N. Y. C & H. R. R. R. Albany, N. Y.	Nov. 20, 1895
DUNCAN, JOHN D. E.	81 Maplewood Ave, Pittsfield, Mass.	Mar. 20, 1895
DUNCAN, THOMAS	Electrician, Laboratory Fort Wayne Electric Corporation, 407 Broadway, Fort Wayne, Ind.	Oct. 17, 1894
DUNLAP, WILL KNOX	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	Sept. 25, 1895
DUNN, KINGSLEY G.	Electrician, 232 Montgomery St., San Francisco, Cal.	Oct. 17, 1894
DURANT, EDWARD	Electrician, Gas Engine Plants for Electric Light and Heat, 39 Cortlandt St.; residence, 115 East 26th St., New York City.	Nov. 15, 1892

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Name.	Address.	Date of Election.
DURANT, GEO. F.	Vice-Pres't Bell Telephone Co., of Mo., 511 No. 4th St., St. Louis, Mo.	April 15, 1884
DYER, FRANCIS MARON	Associate Engineer with Chas. L. Eidlitz, 10 West 23d St ; residence, 355 Lenox Ave., New York City.	Sept. 19, 1894
EDDY, H. C.	Electrical Engineer and Contractor, Lees Building, Chicago, Ill.	June 20, 1894
EDEN, MORTON EDWARD	Electrical Inspector, Western District the Underwriters' Association of the Middle Department, Philadelphia, Pa.; residence, 83 Fourth Ave., Pittsburg, Pa.	Sept. 19, 1894
EDGAR, C. L.	General Manager and Chief Engineer, Edison Elec. Ill'm'g Co., 3 Head Place, Boston, Mass.	Jan. 22, 1896
EDWARDS, JAMES P.	Electrical Engineer, 1569 Walton Way, Augusta, Ga.	April 19, 1892
EGLIN, WM. C. L.	Chief of Electrical Department, Edison Electric Light Co., 909 Walnut St.; residence, 4230 Chester Ave., Philadelphia, Pa.	Sept. 19, 1894
EIDLITZ, CHAS. L.	10 West 23d St.; residence, 1125 Madison Ave., New York City.	Sept. 19, 1894
EKSTRØM, AXEL	Electrical Engineer, General Electric Co.; residence, 92 Hamilton Ave., Lynn, Mass.	June 17, 1890
ELEY, HARRIS H.	Electrical Workshop Supt. W. C. & S. W. Telephone Co., 88 Colston St., Bristol, Eng.	Jan. 7, 1890
ELLICOTT, EDWARD B.	Superintendent of Construction, Western Electric Co., 4438 Ellis Ave., Chicago, Ill.	Sept. 19, 1894
LMER, WILLIAM, JR.	Electrical Engineer, Trenton Iron Co., Trenton, N. J.	Mar. 18, 1890
ELY, WM. GROSVENOR, JR.	72 Washington Ave., Schenectady, N. Y.	Mar. 21, 1893
EMMET, HERMAN L. R.	Publisher and Printer, 36 Cortlandt St., New York City.	April 15, 1884
ENDE, SIEGFRIED H.	148 E. 84th St., New York City.	Jan. 17, 1894
ENTZ, JUSTUS BULKLEY	Electrical Engineer, Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia, Pa.	Jan. 7, 1890
ERICKSON, F. WM.	Edison Electric Illuminating Co., 3 Head Place, Boston, Mass.	Sep. 19, 1894
ESSICK, SAMUEL V.	Electrician, Consolidated Telegraph and News Co., 53 Park Place, New York; residence, Yonkers, N. Y.	May 19, 1891
ESTY, WILLIAM	Assistant Professor of Electrical Engineering, State University, Urbana, Ill.	Mar. 20, 1895
ETHERIDGE, LOCKE	Chicago Telephone Co.; residence, 4714 Kenwood Ave., Chicago, Ill.	Oct. 17, 1894

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Name.	Address.	Date of Election.
ETHERIDGE, E. L.	Care of J. P. Hall, 143 Liberty St., New York City.	Dec. 20, 1893
EVANS, EDWARD A.	Acting Chief Engineer, The Quebec, Montmorency and Charlevoin Railway, Quebec, Canada.	Jan. 22, 1896
EYRE, M. K.	Assistant to Manager of Lamp Sales, General Electric Co., Harrison, N. J.	Oct. 17, 1894
FARNSWORTH, ARTHUR J.	Chief Engineer, Larchmont Electric Co., Mamaroneck, N. Y.	Jan. 16, 1895
FAY, THOMAS J.	"C. & C." Electric Co., 143 Liberty St., New York City.	June 26, 1891
FIELDING, FRANK E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
FISCHER, GUSTAVE J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	Jan. 20, 1891
FISHER, HENRY W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	Jan. 16, 1895
FISKE, HENRY G.	Electrician, 45 E. 22d St., New York City.	Nov. 12, 1889
FISKE, J. P. B.	Railway Engineering Dep't, General Electric Co., Schenectady, N. Y.	June 17, 1890
FLAGG, STANLEY G., JR.	Stanley G. Flagg & Co., 19th St., and Penna. Ave., Philadelphia, Pa.	April 18, 1893
FLANAGAN, THOMAS FRANCIS	Supt. and Electrician, Portsmouth Gas Light Co., Portsmouth, N. H	Jan. 17, 1894
FLATHER, JOHN J.	Professor of Mechanical Engineering, Purdue University, Lafayette, Ind.	April 19, 1892
FLEGEL, GEO. C.	East Chicago, Ind.	Sept. 20, 1893
FLEMING, RICHARD	Electrician, Navy Yard, N. Y.; residence, Jamaica, N. Y.	Oct. 18, 1893
FLESCH, CHARLES	Electrical Engineer, Allgemeine Elektricitats-Gesellschaft, 22 Schiffbauerdamm, Berlin, N. W. Germany.	Sept. 27, 1892
FLINT, BERTRAM P.	Electrical and Mechanical Engineer, Supt. Washington, Alexandria and Mt. Vernon Electric Railway Co., Washington, D. C.	Jan. 17, 1894
FLOOD, J. F.	Sup't Steubenville Traction Co., Steubenville, O.	Mar. 18, 1890
FLOY, HENRY	Engineering Dep't Westinghouse Electric and Mfg. Co., Pittsburg; residence, Edgewood Park, Pa.	May 17, 1892
FOOTE, ALLEN R.	Export Journal, New York City.	April 21, 1891
FOOTE, CHARLES W.	Consulting Electrical Engineer, Pomona, Cal.	Sept. 22, 1891
FOOTE, THOS. H.	Electrical Engineer, C & C. Electric Co., Garwood, near Westfield, N. J.	April 21, 1891
FORBES, FRANCIS	Lawyer, 32 Nassau St., New York City.	Sept. 16, 1890

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Name.	Address.	Date of Election.
FORBES, GEORGE	Electrical Engineer, 34 Great George St., London, Eng.	Feb. 21, 1894
FORD, WM. S.	Assistant to Chief Engineer, The American Bell Telephone Co., Room 73, 125 Milk St., Boston, Mass.	June 7, 1892
FORTENBAUGH, S. B.	Asst. Prof. of Electrical Engineering, University of Wisconsin, Madison, Wis.	April 17, 1895
FOSTER, SAMUEL L.	Electrical Engineer, Market St. Railway Co. 19 Hobart Bldg.: residence, 839 24th St., San Francisco, Cal.	Feb. 26, 1896
FRANCISCO, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890
FRANTZEN, ARTHUR	Electrical Contractor, 353 Dearborn St., Chicago, Ill.	Feb. 21, 1894
FRENCH, PROF. THOMAS, JR. *Ph.D.*	Avondale, Cincinnati, O.	Sept. 20, 1893
FRENYEAR, THOMAS C.	Westinghouse Electric and Mfg. Co., Erie County Bank Bldg., Buffalo, N. Y.	Sept. 25, 1895
FREY, CHARLES P.	Electrician. The E. S. Greeley & Co., 5 and 7 Dey St., New York City.	June 6, 1893
FRIDENBERG, HENRY LESLIE, *M. E.*	Stanley Mfg. Co., (Meter Dept.,) Pittsfield, Mass.	Jan. 16, 1895
FRIEDLAENDER, EUGENE	Electrician, Carnegie Steel Company, Duquesne, Pa.	Nov. 20, 1895
FROST, FRANCIS R.	Westinghouse Electric and Mfg. Co., 427 South Ave., Wilkinsburg, Pa.	Dec. 20, 1893
FROST, JOSEPH W.	Secretary, National Automatic Fire Alarm, 335 Broadway, New York City.	Mar. 20, 1895
FULLER, FRANK G.	Meriden, Ct.	Oct. 19, 1894
FULLER, LEVI K.	Vice-President, Estey Organ Co., Brattleboro, Vt.	Mar. 5, 1889
GALLAHER, EDWARD B.	Consulting and Supervising Engineer, 99 Cedar St.: residence, 1190 Madison Ave., New York City.	Jan. 19, 1895
GALLETLY, J. FRED.	Electrician, Swift & Co., Chicago, Ill.	Mar. 21, 1894
GARRELS, W. L.	4531 West Pine Boulevard, St. Louis, Mo.	Mar. 20, 1895
GERRY, JAMES H.	Superintendent, The Self-Winding Clock Co., 163 Grand Ave., Brooklyn, N. Y.	April 18, 1894
GERRY, M. H., JR.	Supt. of Motive Power, The Metropolitan West Side Elevated Railroad Co., 146 Throop St., Chicago, Ill.	April 18, 1893
GERSON, LOUIS JAY	President and Electrical Engineer, The Gerson Electrical Mfg. Co., 804 Walnut St.; residence, Lansdowne, Pa.	Sept. 19, 1894
GHERARDI, BANCROFT, JR.,	Assistant in the Engineering Dept. Metropolitan Tel. & Tel. Co.; residence, 30 East 33d St., N. Y. City.	June 27, 1895
GILES, WALTER A.	Goubert Mfg. Co., 29 Cortlandt St., New York City.	Nov. 1, 1887

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Name.	Address.	Date of Election
GILLILAND, E. T.	Pelham Manor, N. Y.	April 15, 1884
GILMORE, LUCIEN H.	Prof. of Physics and Electrical Engineering, Throop Polytechnic Institute, Pasadena, Cal.	Mar. 20, 1895
GLADING, FRANK W., *M. E.*, *M. S.*	Lecturer on Electricity, 2005 E. York St., Philadelphia, Pa.	May 15, 1894
GLADSTONE, JAMES WM.	Manager, Edison Mfg. Co., 110 East 23d St.; residence, West Orange, N.J.	April 18, 1894
GOLDMARK, CHAS. J.	Electrical Engineer, 49 Liberty St, and 473 Park Ave., New York City.	June 5, 1888
GOLDSBOROUGH, WINDER E., *M.E.*,	Associate Professor of Electrical Engineering, Purdue University, Lafayette, Ind.	Mar. 21, 1893
GORTON, CHARLES	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
GORDON, REGINALD	Tutor in Physics, Columbia College, residence, 339 Lexington Ave., New York City.	Feb. 24, 1891
GOSSLER, PHILIP G.	Electrical Engineer, Royal Electric Co. 94 Queen St., Montreal, P. Q.	June 20, 1894
GOTT, CLARENCE P.	Chief Engineer and Electrician Grand Central Palace; residence, 83 Washington Place, New York City.	Nov. 20, 1895
GRAHAM, GEORGE WALLACE	741 Marcy Ave., Brooklyn, N. Y.	Dec. 19, 1894
GRAY, W. N.	Electrical Engineer, 200 Neave Building, Cincinnati, O.	Oct. 1, 1889
GRIFFES, EUGENE E.	Senior Partner, Firm of Griffes and Summer, 307 South Main St., Los Angeles, Cal.	Feb. 26, 1896
GRIFFIN, CAPT. EUGENE	First Vice-President, General Electric Co., Schenectady, N. Y.; residence, 323 State St, Albany, N. Y.	Feb. 7, 1890
GRIST, JAMES E.	Mechanical Engineer, Pennsylvania Iron Works Co., 50th and Lancaster Ave.; residence, 918 North 44th St., Philadelphia, Pa.	Mar. 20, 1895
GROSS, S. ROSS	Electrician, Tennessee Coal, Iron and R.R. Co., Ensley, Ala.	May 17, 1892
GROWER, GEORGE G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
GUY, GEORGE HELI	Secretary, The New York Electrical Society, 203 Broadway, New York City.	May 16, 1893
HADAWAY, W. S., Jr.	Electric Heating Engineer, 107 Liberty St., New York City.	Nov. 21, 1894
HADLEY, ARTHUR L.	Assistant Electrician to Chief Electrician and Gen'l Supt., Fort Wayne Electric Corporation, 149 Griffith St., Fort Wayne, Ind.	Oct. 17, 1894
HADLEY, WARREN, B.	30 Cortlandt St., New York City.	June 26, 1891
HAKONSON, CARL HAROLD	Ass't Engineer, Gen'l Electric Co., P. O. Box 254, Schenectady, N. Y.	Sept. 25, 1895

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Name.	Address.	Date of Election.
HALL, EDWARD J.	Vice-President and General Manager, American Telephone and Telegraph Co., 18 Cortlandt St ,New York City.	April 18, 1893
HALL, EDWIN H.	Assistant Professor of Physics, Harvard College, Gorham St., Cambridge, Mass.	Sept. 3, 1889
HALL, WILLIAM P.	President, The Hall Signal Co., Vice-President The Johnson Railroad Signal Co., 80 Broadway, New York City.	Sept. 16, 1890
HALSEY, WILLIAM B.	Electrician and Horologist, 246 Elton St., Brooklyn, N. Y.	Mar. 18, 1890
HAMMATT, CLARENCE S.	Supt., Jacksonville Electric Light Co., Jacksonville, Fla.	Sept. 20, 1893
HANCOCK, L. M.	P. O. Box 151. Nevada City, Cal.	May 19, 1891
HARDING, H. McL.	253 Broadway, New York City.	May 24, 1887
HARRINGTON, WALTER E.	Electric Railway Engineer, 307 Market St., Camden, N. J.	Mar. 17, 1891
HARRIS, GEORGE H.	Electrical Engineer. Birmingham Railway and Electric Co., Birmingham, Ala.	June 20, 1894
HARRIS, W. C., JR.	Electrician, Harris & Williamson, Birmingham, Ala.	April 17, 1895
HARRISON, HAROLD	New York Representative, Slater Engine Co., Montclair, N. J.	Feb. 21, 1894
HARRISON, RUSSELL B.	Pres. and Electrical Engineer, Terre Haute Electrical Railway Co., Terre Haute, Ind.	Sept. 25, 1895
HART, FRANCIS R.	President and General Manager, Cartagena-Magdalena Railway Co., care of Old Colony Trust Co., 1 Court St., Boston, Mass.	April 21, 1891
HARTMAN, HERBERT T.	Works Engineer, Peterborough Factory, Canadian General Electric Co., Peterborough, Ont.	Mar. 21, 1893
HARVEY, ROBERT R. [Life Member.]	10 So. Franklin St., Wilkes-Barre, Pa.	Sept. 25, 1895
HATZEL, J. C.	Electrical Engineer and Contractor, 114 Fifth Ave., New York City.	Sept. 3, 1889
HAVILAND, FOSTER L.	19 Beekman Street; residence, 163 St. Nicholas Ave., New York City.	May 15, 1894
HEATH, HARRY E.	Assistant Electrical Engineer, Eddy Electric Mfg. Co., Box 189, Windsor, Conn.	Mar. 21. 1893
HEALY, LOUIS W.	Mechanical Engineer's Office, Altoona, Pa.	June 26, 1891
HEDENBERG, WM. L.	Firm of Hedenberg & Kinsey, Consulting and Constructing Engineers, 108 Fulton St.; residence, 83 Clinton Place, New York City.	Nov. 21, 1894
HENDERSON, HENRY BANKS	Graduate Student Cornell University, 686 Willoughby Ave., Brooklyn, N. Y.	May 21, 1895
HERDMAN, FRANK E.	Mechanical and Electrical Engineer, Crane Elevator Co., Winnetka, Ill	Dec. 18, 1895

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Name.	Address.	Date of Election.
HESSENBRUCH, GEORGE S.	Student at the College at Berlin, Berliner Str. 75, Charlottenburg, Germany.	Sept. 25, 1895
HEWITT, CHARLES E.	Electrician, Hyer-Sheehan Electric Motor Co., 100 Johnson St., Newburgh. N. Y.	Sept. 25, 1895
HEWITT, WILLIAM R.	Superintendent, Fire Alarm and Police Telegraph, 9 Brenham Place, San Francisco, Cal.	May 15, 1894
HEWLETT, EDWARD M.	Electrical Engineer, Railway Dept. General Electric Co., Schenectady, N. Y.	May 19, 1891
HILL, GEORGE, *C.E.*	Consulting Engineer, 44 Broadway, New York City.	April 19, 1892
HISS, WM. J., JR.,	Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., New York, residence, 44 Munn Ave., East Orange, N. J.	Mar. 20, 1895
HOBART, HENRY M.	Engineer, General Electric Co., Schenectady, N Y.; residence. 242 Massachusets Ave., Boston, Mass.	April 18, 1894
HOCHHAUSEN, WILLIAM	Electrician, 74 Hanson Pl., Brooklyn, N. Y.	April 15, 1884
HOLBERTON, GEORGE C.	Engineer, Oakland Gas Light and Heat Co., 13th and Clay Sts., Oakland, Cal.	May 15, 1894
HOLCOMB, EUGENE R.	[Address unknown.]	June 17, 1890
HOLLERITH, HERMAN	Hollerith Electric Tabulating System, 1054 31st St., Washington, D. C.	Sept. 19, 1894
HOLT, MARMADUKE BURRELL,	Mining and Electrical Engineer, 287 Lexington Ave. New York, N.Y.	April 15, 1890
HOOD, RALPH O.	Electrical Engineer, Danvers, Mass.	April 18, 1894
HOPKINS, NEVIL MONROE	Scientific Literature, 1730 I Street, Washington, D. C.	Nov. 20, 1895
HORNSBY, HARRY H.	Electrical Inspector, 16 City Hall, Chicago, Ill.	June 27, 1895
HOWSON, HUBERT	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
HUBBARD, ALBERT S.	Electrical Engineer. Alexander-Chamberlain Electric Co.; residence, 223 E. 36th St., New York City.	Nov. 20, 1895
HUBBARD, WILLIAM C.	Engineering Department. Marks-Ayer Electric Co.. 73 Watts St., New York City; residence. 109 West 5th St., Plainfield, N. J.	April 18, 1894
HUBLEY, G. WILBUR	Electrical Engineer, Louisville Electric Light Co.; residence, Kenton Club, Louisville, Ky.	Sept. 19, 1894
HUBRECHT, DR. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
HUDSON, JOHN E.	President, The American Bell Telephone Co., 125 Milk St., Boston, Mass.	Dec. 20, 1893.

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Name.	Address.	Date of Election.
HUGUET, CHAS. K.	Westinghouse E. & M. Co., East Pittsburg, Pa.; residence, 745 Wallace Ave., Wilkinsburg, Pa.	June 27, 1895
HUMPHREYS, C. J. R.	Manager, Lawrence Gas Co., and Edison Electrical Ill. Co., Lawrence. Mass.	Sept. 6, 1887
HUNT, ARTHUR L.	Electrician, W. R. Fleming & Co., 203 Broadway, New York City.	Sept. 19, 1894
HUNTLEY, CHAS. R.	General Manager, Buffalo General Electric Co., 40 Court St., Buffalo, N. Y.	Sept. 25, 1895
HUTCHINSON, FREDERICK L.	Electrical Engineer with Westinghouse Electric and Mfg. Co., East Pittsburg, Pa.	June 20, 1894
IDELL, FRANK E.	Havemeyer Building, 26 Cortlandt St., New York City.	July 12, 1887
IHLDER, JOHN D.	Electrical Engineer, Otis Electric Co., Yonkers, N. Y.	Oct. 2, 1888
IIJIMA ZENTARO,	Assistant, Wagner Elec. Mfg. Co., 2017 Lucas Place, St. Louis, Mo.	Jan. 22, 1896
INGOLD, EUGENE	Consulting Engineer and Expert, 1669 Second Ave., Pittsburg, Pa.	April 18, 1894
INSULL, SAMUEL	President, Chicago Edison Co., 513 Rookery, Chicago, Ill.	Dec. 7, 1886
IWADARE, KUNIHIKO	Electrician, 19 Second St., Nakanoshima, Japan.	Sept. 20, 1893
IZARD, E. M.	Electrical Engineer, Room 1409, 315 Dearborn St., Chicago, Ill.	Mar. 5, 1889
JAEGER, CHARLES L.	Inventor, Maywood, N. J.	Dec. 20, 1893
JACKSON, THEODORE K.	Siemens and Halske Electric Co. of America; residence, 137 56th Street, Chicago, Ill.	May 21, 1895
JOHNSTON, W. J.	*The Electrical World*, 253 Broadway. New York City.	April 15, 1884
JONES, ARTHUR W.	Care of H. H. Kingsbury, Sydney, N. S. W.	Oct. 17, 1894
JONES, F. R.	Professor of Machine Design, University of Wisconsin, Madison, Wis.	May 20, 1890
JONES. G. H.	Agent, General Electric Co., Casilla 18 D Santiago; residence, Iquiqui, Chili.	April 17, 1895
JONES, HENRY C.	Member of Firm, the Electric Construction and Supply Co., Montgomery, Ala.	Mar. 20, 1895
JUDSON, WM. PIERSON	U. S. Civil Engineer, Oswego, N. Y.	June 8, 1887
KAMMEYER, CARL E.	Electrical Engineer, Maywood Ill.	Sept. 19, 1894
KEEFER, EDWIN S.	Supt. of Electric Light Construction, Western Electric Co., 22 Thames St., New York City; residence, Elizabeth, N. J.	April 18, 1894
KEILHOLTZ, P. O.	U. S. Electric Power and Light Co., Holliday and Centre Sts., Baltimore, Md.	Mar. 21, 1893

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Name.	Address.	Date of Election.
KELLER, CHAS. L.	5940 East End Ave., Chicago, Ill.	Oct. 17, 1894
KELLER, E. E.	Vice-Prest. and General Manager, Westinghouse Machine Co, 224 Murtland Ave., Pittsburg, Pa.	Sept. 20, 1893
KELLER, EDWIN R., *M.E.*	Mechanical and Electrical Engineer, Falkenau Engineering Co., Ltd., 711 Reading Terminal, 4823 Springfield Ave., Philadelphia, Pa.	Mar. 21, 1894
KELLOGG, JAMES W., *M.E.*	General Electric Co., Lighting Dept., Schenectady, N. Y.	June 26, 1891
KENNELLY, ARTHUR E. [Life Member.]	(*Manager.*) Electrician, Firm of Houston & Kennelly, 1105–1106 Betz Bldg.; residence, The Landsowne, 41st St. and Elm Ave., Philadelphia, Pa.	May 1, 1888
KER, W. WALLACE	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant St., New York City. Residence, 43 Waverly St., Jersey City, N. J.	Sept. 25, 1895
KIRKEGAARD, J. GEORG	Mechanical and Electrical Engineer, 106 Fulton Street, New York City; residence, Giffords, Staten Island, N. Y.	Sept. 20, 1893
KIRKLAND, JOHN W.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 21, 1894
KLINCK, J. HENRY	Dept. Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Jan. 16, 1895
KNOX, FRANK H.	With C. J. Ryan, Croton-on-Hudson, N. Y.	June 20, 1894
KNOX, JAMES MASON	Student in Electrical Engineering, Columbia College, School of Mines; Residence, 32 West 129th St., New York City.	Jan. 17, 1894
KREIDLER, W. A.	Editor and Publisher, *Western Electrician*, 510 Marquette Building, Chicago, Ill.	Oct. 4, 1887
LAMB, RICHARD	Chief Engineer, in charge business of the Lamb Electrical Cableways. The Trenton Iron Co., No. 1 Broadway; residence, 72 W. 69th St., New York.	Dec. 18, 1895
LAND, FRANK	Globe Hotel, Syracuse, N. Y.	Sept. 22, 1891
LANE, VANCE	Manager and Superintendent Construction, Nebraska Telephone Co., Omaha, Neb.	Dec. 19, 1894
LANPHEAR, BURTON S.	Instructor in Electrical Engineering, Maine State College, Orono, Me.	Jan. 16, 1895
LANMAN, WILLIAM H.	Patent Dept., General Electric Co., 44 Broad St., New York City.	June 6, 1893
LARDNER, HENRY ACKLEY	Instructor in Electrical Engineering, State College, Penn.	Dec. 19, 1894
LARNED, SHERWOOD J.	Electrical Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	Oct. 17, 1894
LARRABEE, ROLLIN N.	Marble City Electric Co., Rutland, Vt.	Mar. 20, 1895

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Name.	Address.	Date of Election.
LAWTON, W. C.	Roselle, N. J.	June 6, 1893
LEBLANC, CHARLES	European Agent of the Walker Mfg. Co of Cleveland, O.; 24 Boulevard des Cepacines, Paris. France.	April 17, 1895
LECONTE, JOSEPH NISBET	Instructor in Electrical Engineering, State University, Berkeley, Cal.	Feb. 27, 1895
LEDOUX, A. R., *M. S.*, *Ph.D.*,	9 Cliff St., New York City.	Dec. 7, 1886
LEE, JOHN C.	Chemist and Electrician, American Bell Telephone Co., Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
LENZ, CHARLES OTTO	Electrical Engineer, Room 510, Industrial Trust Bldg., Providence, R. I.	Mar. 15, 1892
LE PONTOIS, LEON.	Electrical Engineer, The Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	Dec. 18, 1895
LESLIE, EDWARD A.	Vice-President and Manager, Manhattan Electric Light Co., Ltd., New York City; residence, 343 Hancock St., Brooklyn, N. Y.	Jan. 16, 1895
LESTER, WILLIAM B.	Western Union Telegraph Co., 195 Broadway; residence, 346 Lenox Ave., New York City.	Jan. 16, 1895
LEVIS, MINFORD	Superintendent, and Electrical Engineer, Novelty Electric Co., 54 North 4th St., Philadelphia, Pa.	Feb. 21, 1893
LEVY, ARTHUR B.	Assistant Engineer, Arc Light Dept., General Electric Co., 810 Lexington Ave., New York City.	Jan. 20, 1891
LEWIS, HENRY FREDERICK	WILLIAM, Redlands, 48 Sydenham Road, Croydon, Surrey, England.	Mar. 5, 1889
LIEBIG, GUSTAV A., JR.	Tarrytown, N. Y.	Mar. 6, 1888
LILLEY, L. G.	Electrical Inspector, Underwriters' Association of Cincinnati, S. W. Cor. 3d and Walnut Sts., Cincinnati, O.; residence, Wyoming, O.	June 20, 1894
LINCOLN, PAUL M.	Electrician-in-charge, Cataract Construction Co., Niagara, Falls, N. Y.	Sept. 25, 1895
LINDNER, CHAS. T.	Martin & Lindner, Electrical Engineers, Luning Building, San Francisco, Cal., residence, Berkeley, Cal.	Dec. 20, 1893
LINDSAY, WM. E.	Chief Engineer and Electrician, Swift & Co, National Stock Yards, East St. Louis, Ill.	April 17, 1895
LLOYD, JOHN E.	Assistant Chief Engineer, Philadelphia Traction Co.; residence, 2008 N. 18th, St., Philadelphia, Pa.	Jan. 22, 1896
LOEWENHERZ, HERMAN	Assistant to Engineer, Met. Tel. and Tel. Co., 18 Cortlandt St., New York City; residence, 311 Hudson St., Hoboken.	Feb. 27, 1895
LOOMIS, OSBORN P.	Electrical Engineer, Bound Brook, N. J.	Sept. 16, 1890
LOW, GEORGE P.	Consulting Electrical Engineer, Electrical Inspector, Pacific Insurance Union, 303 California St., San Francisco, Cal.	Jan. 17, 1893

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Name.	Address.	Date of Election.
LOZIER, ROBERT T. E.	Electrical Engineer, 150 Nassau St., New York City.	May 20, 1890
LUDLAM, HARRY W.	With Western Electric Co.; residence, 480 Lexington Ave., New York City.	Dec. 18, 1895
LUFKIN, HARVEY L.	Crocker-Wheeler Electric Co., 39 Cortlandt St., New York City.	June 17, 1890
LUNDELL, ROBERT	Electrical Engineer, Interior Conduit and Insulation Co., 527 W. 34th St., New York; residence, 47 Brevoort Pl., Brooklyn, N. Y.	Feb. 7, 1890
LUQUER, THATCHER, T. P.	Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., residence, Bedford, N. Y.	June 26, 1891
LYMAN, CHESTER WOLCOTT, *M. A.*	Manager Herkimer Paper, Co., Herkimer, N. Y.	Sept. 19, 1894
LYMAN, JAMES [Life Member.]	1 North College Street, Schenectady, N. Y.	Sept. 19, 1894
MACCOUN, ELLICOTT	Ass't Supt. of the Electrical Dept. The Carnegie Steel Co., Munhall, Pa.	Nov. 20, 1895
MACCULLOCH, ROBERT C.	Manager, Jos. Lough Electric Co., 503 Fifth Ave.; residence, 209 W. 81st St., New York City.	Feb. 27, 1895
MACFADDEN, CARL K.	Electrical Engineer, Gas Engine Dep't Western Gas Construction Co., Fort Wayne, Ind.	Sept. 27, 1892
MACKIE, C. P.	44 Broad St., New York City; residence, Englewood, N. J.	Mar. 21, 1893
MACMULLAN, ROBERT HEATH, Lafayette, Ind.		Sept. 22, 1891
MACQUESTEN, W. D.	Electrical Engineer and Contractor, Room 25, 15 Cortlandt St., New York City.	April 15, 1890
MADDEN, OSCAR E.	41 and 43 Wall St., New York City.	April 15, 1884
MAGEE, LOUIS J.	Electrical Engineer, Director, der Union Elektricitats Gesellschaft, Corneliusstr 1., Berlin, W. Germany.	April 2, 1889
MALCOLM, PHILIP S.	Electrical Engineer and Contractor, 131 Sixth St., Portland, Ore.	Mar. 18, 1890
MALIA, JAMES P.	Electrician, Armour & Co., 5314 Union Ave., Chicago, Ill.	June 20, 1894
MANN, FRANCIS P.	Maison Breguet, 19 Rue Didot, Paris, France.	June 6, 1893
MANN, ROBERT BRUCE	643 Franklin St., Milwaukee, Wis.	Sept. 25, 1895
MARTIN, A. J.	Complete Electric Construction Co., 121 Liberty St., New York City.	Mar. 15, 1892
MARTIN, FRANK	Electrical Engineer, Madison Square Garden Company, New York City.	Oct. 21, 1890
MARTIN, T. COMMERFORD (*Past-President.*)	Editor, *The Electrical Engineer*, 203 Broadway, New York City.	April 15, 1884
MASON, JAMES H.	Electrical Expert, 10 Fifth Ave., Brooklyn, N. Y.	May 19, 1891

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Name.	Address.	Date of Election.
MATTHEWS, CHARLES P.	Instructor in Physics, Cornell University, Locust Grove, Ithaca, N. Y.	May 16, 1893
MAURO, PHILIP	Counsellor at-Law in Patent Causes (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
MAYER, MAXWELL M.	Mfr. of Dynamos and Motors, 411 107th St., E. R.; residence 242 East 114th St., New York City.	Feb. 27, 1895
MAYRHOFER, JOS. CARL	Electrical Engineer, 165 W. 82d St., New York City.	June 20, 1894
MCBRIDE, JAMES	Superintendent, N. Y. & Boston Dye Wood Co., 146 Kent St., Brooklyn, N. Y.	Sept. 27, 1892
MCCARTHY, LAWRENCE A.	Western Union Telegraph Co., New York City, 1053 Bedford Ave., Brooklyn, N. Y.	Jan. 19, 1892
MCCLURG, W. A.	Manager, Electrical Dept., Plainfield Gas and Electric Light Co., 207 Madison Ave., Plainfield, N. J.	Dec. 20, 1893
MCCROSKY, JAMES W.	Electrical Engineer, La Capital Tramway Co., 715 Avenida di Mayo, Buenos Aires, Argentina.	Dec. 20, 1893
MCELROY, JAMES F.	Mechanical Supt., The Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
MCKAY, C. R.	Consulting Engineer, 140 South Main St., Salt Lake City, Utah.	Dec. 20, 1893
MCKIBBIN, GEORGE N.	Reed & McKibbin, General Street Railway Contractors, 80 Broadway, New York City.	June 8, 1887
MCKINSTRY, J. P.	General Manager, Cleveland Telephone Co., 316 Seneca St., Cleveland, O.	April 15, 1884
MCKISSICK, A. F.	Professor of Electrical Engineering, The A. & M. College of Ala., Auburn, Ala.	Feb. 16, 1892
MCMEEN, SAMUEL G.	Assistant Engineer, Central Union Telephone Co., 1306 Ashland Block, Chicago. Ill.	Dec. 18, 1895
MCRAE, AUSTIN LEE	Professor of Physics, University of Texas, Austin, Texas.	May 17, 1892
MEDINA, FRANK P.	Electrician, Pacific Postal Telegraph Co., 534 Market St., San Francisco, Cal.	Sept. 19, 1894
MERCER, ANDREW G.	Electrician, Waterloo Electric Co., Waterloo, N. Y.	Sept. 3, 1889
MEREDITH, WYNN	Electrical Engineer, Hasson & Hunt, 310 Pine St., San Francisco, Cal.	Jan. 17, 1894
MERRILL, E. A.	Electrical Engineer, Pierce & Miller Engineering Co., 26 Cortlandt St., New York City.	Sept. 20, 1893
MERRILL, JOSIAH L.	Ass't to Estimating Engineer of the Construction Department, General Elec. Co., Schenectady, N. Y.	Sept. 25, 1895

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Name.	Address.	Date of Election.
MERRITT, ERNEST	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	Sept. 16, 1890
MERZ, CHAS. H.	British Thomson-Houston Ltd., 38 Parliment St., London, S. W.; residence, The Quarries, Newcastle-on-Tyne, England.	Sept. 25, 1895
MEYER, JULIUS	Consulting Engineer, 44 Broad St., New York City.	Oct. 25, 1892
MIDDLEMISS, P. R.	Post Graduate Student, Mech. and Elec. Engineering, Hotel Germania, Schenectady, N. Y.	Mar. 20, 1895
MILLER, JOSEPH A.	Civil and Consulting Engineer, 25 Butler Exchange, Providence, R. I.	Dec. 9, 1884
MILLER, WM. C., *M. S.*	Electrical Engineer, 3 South Hawk St., Albany, N. Y.	Oct. 21, 1890
MINER, WILLARD M.	Electrician and Inventor, 428 East Sixth St., Plainfield, N. J.	July 12, 1887
MITCHELL, JAMES	Constructing Engineer and Agent, General Electric Co., Caixa do Correio No. 954, Rio de Janeiro, Brazil.	Sept. 25, 1895
MITCHELL, SIDNEY Z.	Manager, Oregon, Washington and Idaho Agency, General Electric Co., Fleischner Building, Portland, Ore.	Nov. 12, 1889
MOORE, WM. E.	Electrician and Sup't. The Augusta Railway Co., Augusta, Ga.	Jan. 22, 1896
MONELL, JOSEPH T.	Consulting Electrical Engineer, 236 W 22d St., New York City.	Oct. 27, 1891
MORA, MARIANO L., *C. E*, *E. E.*,	63 West 70th Street, New York City.	Mar. 20, 1895
MORDEY, WM. MORRIS	Electrician, Brush Electrical Engineering Co., Redholm, Loughborough, London, Eng.	Sept. 22, 1891
MOREHOUSE, H. H.	General Manager and Electrician, Alumbrado Electrico de Quezaltenango, Apartado, No. 44, Quezaltenango, Guatemala, C. A.	Feb. 21, 1894
MORLEY, EDGAR L.	Sup't Hatzel & Buehler, 114 5th Ave., New York City.	Sept. 25, 1895
MORRISON, J. FRANK	15 South St., Baltimore, Md.	April 15, 1884
MORSE, GEORGE H.	Wagner Electric Mfg. Co. St. Louis, Mo.	May 15, 1894
MORSS, EVERETT	Vice-President, Simplex Electric Co., 303 Marlboro St., Boston, Mass.	Sept. 22, 1891
MORTON, HENRY, *Ph.D.*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
MOSES, DR. OTTO A.	Electrician, 1037 Fifth Ave., New York City.	May 17, 1887
MOSES, PERCIVAL ROBERT, *E. E.*	Sprague Electric Elevator Co., 253 Broadway: residence, 46 West 97th St., New York City.	Dec. 19, 1894
MOSMAN, CHAS. T.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	Mar. 20, 1895

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Name.	Address.	Date of Election.
MOSSCROP, WM. A., *M.E*	Electrical Engineer, 189 Montague St., Brooklyn, N. Y.	May 7, 1889
MOTT, S. D.	Electrical Engineer and Inventor, Passaic, N. J.	Sept. 20, 1893
MOTTRAM, WILLIAM T. M.	Electrical Engineer, Room 416, Trust Building, Dallas, Tex.	Mar. 21, 1893
MUNNS, CHAS. K.	Electrician, Strowger Autom. Tel. Exchange, 947 Rookery, Chicago, Ill.	Nov. 21, 1894
MUSTIN, HERBERT S.	[Address unknown.]	Dec. 20, 1893
MYERS, GEO. FRANCIS	Inventive Engineer, Penn Building, Pittsburg, Pa.	June 17, 1890
MYERS, L. E.	Secretary and Treasurer, Electrical Installation Co., 917 Monadnock Building, Chicago, Ill.	Sept. 19, 1894
NEWELL, ARTHUR J.	Electrical Engineer, R. T. Oakes & Co., 366 High St., Holyoke, Mass.	Mar. 18, 1890
NICHOLSON, WALTER W.	General Supt. Central N. Y. Telephone and Telegraph Co., 73 Howard Ave., Utica, N. Y.	May 15, 1894
NICHOLS, GEO. P.	Partner, Geo. P. Nichols & Bro., Elec. Engineers and Contractors, 1036 Monadnock Building, Chicago, Ill.	Jan. 22, 1896
NORTON, ELBERT F.	Chief Inspector, City Electrical Inspection, 175 Dearborn St., Chicago, Ill.	Dec. 20, 1893
NOXON, C. PER LEE	Contracting Electrical Engineer, 504 Townsend St., Syracuse, N. Y.	Oct. 17, 1894
NUNN, RICHARD J., *M.D.*	Physician, 119½ York St., Savannah, Ga.	July 12, 1887
NUTTING, SAMUEL E.	Electrician and Supt., Nutting Electric Mfg. Co., 241 South Scoville Ave.; residence, Oak Park, Ill.	Sept. 20, 1893
NYHAN, J. T.	Superintendent and Electrician, Macon and Indian Spring Electric Railway, Macon, Ga.	Feb. 27, 1895
OCKERSHAUSEN, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887
O'DEA, MICHAEL TORPEY	Professor of Applied Electricity, University of Notre Dame, Notre Dame, Ind.	June 8, 1887
OLAN, THEODOR, J. W.	Civil and Electrical Engineer, 65 West 49th St., New York City.	May 16, 1893
OLIVETTI, CAMILLO	Ingegnere Industriale, Ivrea, Italy.	Oct. 17, 1894
ORMSBEE, ALEX. F.	Electrical Engineer; residence, 183 Joralemon St., Brooklyn, N. Y.	June 27, 1895
OSBORNE, LOYALL ALLEN	Assistant Superintendent, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Oct. 18, 1893
OSTERBERG, MAX, *E.E.*	Associate Editor *Electric Power*, 27 Thames St., and Fellow in Mechanics, Columbia College, residence, 113 E. 65th St., New York City.	Jan. 17, 1894

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Name.	Address.	Date of Election.
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co.; residence, 227 Mount St., Baltimore, Md.	Mar. 20, 1895
OTTEN, DR. JAN D.	Engineer, Union Elektricitats Gesellschaft, Kurfürstenstrasse 97 III, Berlin, W. Germany.	Nov. 18, 1890
OWENS, R. B.	Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.	June 17, 1890
PADDOCK, B. C., JR.	Assistant in Generating Dept., Edison Elec. Illuminating Co. of Boston; residence, Brookline, Mass.	Feb. 27, 1895
PAGE, A. D.	Assistant Manager, General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892
PARCELLE, ALBERT L.	Electrician and Inventor, 157 Washington St., Boston, Mass.	Dec. 16, 1891
PARKER, HERSCHEL C.	Tutor in Physics, Columbia College, 21 Fort Green Pl., Brooklyn, N. Y.	April 19, 1892
PARMLY C. HOWARD, *S.M.*, *E.E.*	College of the City of New York, 17 Lexington Ave.; residence, 344 W. 29th St., New York City.	Feb. 21, 1893
PARRY, EVAN	Engineer, The British Thomson-Houston Ltd., 52 Glengarry Road, East Dulwich, London, S. E.	Sept. 25, 1895
PARSELL, HENRY V., JR.	31 E. 21st St., New York City.	Nov. 12, 1889
PATTON, PRICE I.	Sheble & Patton, Ltd., 1026 Filbert St.; residence, 3926 Walnut St., Philadelphia, Pa.	Mar. 20, 1895
PECK, EDWARD F.	15 Cortlandt Street, New York City; residence, 87 Monroe St., Brooklyn, N. Y.	May 20, 1890
PECK, SAMUEL C.	Electrician, Apartado 403, City of Mexico, Mexico.	Sept. 6, 1887
PEDERSEN, FREDERICK MALLING	Assistant Electrical Engineer, Crocker-Wheeler Electric Co., Ampere, E. Orange, N. J.; residence, 327 W. 34th St., New York City.	Sept. 20, 1893
PEIRCE, WM. H.	Assistant Manager, Baltimore Smelting and Rolling Co., Keyser Bldg, German and Calvert Sts., Baltimore, Md.	Sept. 7, 1888
PERKINS, FRANK C.	Electrical Engineer and Contractor, 774 Prospect Ave., Buffalo, N. Y.	Oct. 21, 1890
PETTY, WALTER M.	Superintendent Fire Alarm Telegraph, Rutherford, N. J.	May 16, 1893
PFUND, RICHARD	With Western Union Telegraph Co., 195 Broadway, New York City.	April 18, 1893
PHILBRICK, B. W.	Electrician, in charge of Electrical Plant, Hon. Levi P. Morton, Rhinecliff, N. Y.	May 15, 1894
PHILLIPS, EUGENE F.	Manufacturer Insulated Electric Wire, Providence, R. I.	July 13, 1889
PHILLIPS, LEO A.	Westinghouse Electric and Mfg. Co., East Pittsburg, Pa.	Mar. 21, 1894

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Name.	Address.	Date of Election
PHISTERER, FRED'K WILLIAM	Graduate Student, Cornell University; residence, 84 Heustis St., Ithaca, N. Y.	Nov. 20, 1895
PINKERTON, ANDREW	Electrical Engineer, The Apollo Iron and Steel Co., Apollo, Pa.	Sept. 25, 1895
PLUMB, CHARLES	Proprietor and Electrician, The Chas. Plumb Electrical Works, 89 Erie St., Buffalo, N. Y.	June 20, 1894
POOLE, CECIL P.	Care *Electrical World*, 253 Broadway, New York City.	Jan. 3, 1888
POPE, RALPH WAINWRIGHT	Secretary to the American Institute of Electrical Engineers, 26 Cortlandt St., (Telephone, 2199 Cortlandt). New York City; residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885
POTTER, HENRY NOEL	Electrician, Steglitzer Strasse, 10 parterre, Berlin W., Germany.	Sept. 19, 1894
POTTER, WM. BANCROFT,	Engineer Railway Department, General Electric Co., Schenectady, N. Y.	Jan. 22, 1896
POWELL, PERCY HOWARD	Cornell University, Class of '95, residence, Hempstead, N. Y.	Sept. 25, 1895
PRATT, CHARLES A.	Electrical Engineer, The Independent Electric Co., 39th St. and Stewart Ave., Chicago, Ill.	Dec. 19, 1894
PRICE, CHAS. W.	Editor the *Electrical Review*, 13 Park Row, New York City; residence, 223 Garfield Place, Brooklyn, N. Y.	Sept 19, 1894
PRICE, EDGAR F.	Electricial Engineer, Carbide Mfg. Co., Niagara Falls, N. Y.	June 27, 1895
PRINCE, J. LLOYD	868 Flatbush Ave., (Flatbush Station), Brooklyn, N. Y.	Feb. 27, 1895
PRIVAT, LOUIS	Electrician, Cicero Water, Gas and Electric Light Co., Oak Park, Ill.	Dec. 19, 1894
PROCTOR, THOS. L.	General Manager, Riker Electric Motor Co., Brooklyn; residence, Newtown, L. I., N. Y.	April 18, 1894
PUPIN, DR. MICHAEL I.	(*Vice President*) Adjunct Professor in Mechanics, Columbia College; residence, 137 W. 66th St., New York City.	Mar. 18, 1890
RANDALL, JOHN E.	Columbia Incandescent Lamp Co., 1912 Olive St., St. Louis, Mo.	May 7, 1889
RANDOLPH, L. S.	Professor of Mechanical Engineering, Blacksburg, Va.	Feb. 21, 1893
RATHENAU, ERICH	Electrical Engineer, Allg. Electricitats Gesellschaft, Berlin, Germany.	Nov. 20, 1895
RAY, WILLIAM D.	General Manager Everett Railway and Electric Co., Everett, Washington.	Sept. 27, 1892
READ, ROBERT H.	Patent Attorney, 39 Cortlandt St., New York City.	Jan. 19, 1892
REDMAN, GEO. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., Rochester, N. Y.	Feb. 27, 1895

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Name.	Address.	Date of Election.
REED, CHAS. J.	Electrician, 3313 N. 16th St., Philadelphia, Pa.	Mar. 5, 1889
REED, HARRY D.	Electrician, Bishop Gutta Percha Co., 420 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	Sept. 19, 1894
REED, HENRY A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	June 4, 1889
REID, EDWIN S.	Sup't of Construction, National Underground Cable Co, 17 Times Building New York City; residence, 116 W. 11th St.	Feb. 26, 1896
REID, THORBURN	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Oct. 21, 1890
REILLY, JOHN C.	General Supt., N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
REINMANN, A. L.	American Electric Mfg. Co., St. Louis, Mo.	June 8, 1887
RENNARD, JOHN CLIFFORD,	*A. B. E. E.* Consulting and Supervising Electrical Engineer, 136 Liberty St.; residence, 302 W. 73d St., New York City.	Jan. 16, 1895
REQUIER, A. MARCEL	Electrical Engineer, Westinghouse Electric and Manufacturing Co., Pittsburg, Pa.	Dec. 20, 1893
RHODES, S. ARTHUR	Electrician, Chief Testing Department, Chicago Telephone Co, Chicago, Ill.; residence, 429 North Pine Ave., Austin, Ill.	Oct. 17, 1894
RICHARDSON, ALBERT E.	Lecturer in Science, 21 Knight's Park, Kingston-on-Thames, England.	Feb. 21, 1894
RICHARDSON, ROBERT E.	Electrical Engineer, Pierce & Richardson, 1409 Manhattan Building; residence, 3827 Forest Ave, Chicago, Ill.	Sept. 19, 1894
RICKER, CHARLES W.	Expert Electrical Engineer, 184 Cleveland Ave., Buffalo, N. Y.	May 15, 1894
RIDLEY, A. E. BROOKE	Agent, Electrical Engineer, Siemens & Halske Electric Co., 508 California St., San Francisco, Cal.	Nov. 21, 1894
RITTENHOUSE, CHAS. T.	*Electrical World*, 253 Broadway, residence, 247 W. 138th St, New York City.	Feb. 21, 1894
ROBINSON, DWIGHT PARKER	With Stone & Webster, 4 P. O. Square, Boston, Mass.	Sept. 25, 1895
ROBERSON, OLIVER R.	Electrician, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	Dec. 20, 1893
ROBERTS, WM. H.	15 Harrison St., Cincinnati, O.	Sept. 19, 1894
ROBINSON, ALMON	Draughtsman, Expert in Methods of Gearing, Webster Road, P. O. Box 943, Lewiston, Me.	Sept. 6, 1887

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Name.	Address.	Date of Election.
ROBINSON, FRANCIS G.	With Brooklyn Heights R. R. Co.; residence, 156 Macon St., Brooklyn, N. Y.	Nov. 21, 1894
RODMAN, SAMUEL, JR.	(Late 1st Lieut., 2nd U. S. Artillery), Electrician and Expert in High Explosives. Room 106, Pullman, Bldg., Chicago, Ill.	Sept. 16, 1890
ROEBLING, FERDINAND W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887
ROESSLER, S. W.	Captain, Corps of Engineers U. S. A., 99 Madison St., Memphis, Tenn.	Dec. 3, 1889
ROGERS, EDWARD H.	Patent Lawyer, New Haven, Conn.	Sept. 22, 1891
ROLLER, FRANK W. *M.E.*	Electrical Engineer, with J. A. Machado, 203 Broadway, N. Y.; residence, 515 Clinton Avenue, Brooklyn, N. Y.	May 21, 1895
ROLLER, JOHN E.	Lieut. U. S. N., in charge of Inspection and Installation, U. S. Navy Yard, New York: residence, 515 Clinton Ave., Brooklyn, N. Y.	Sept. 19, 1894
ROPER, DENNEY W.	Electrician with the Niagara Falls Power Co., 239 Fifth St., Niagara Falls, N. Y.	June 6, 1893
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, Toronto, Ont.	June 26, 1891
ROSENBAUM, WM. A.	Electrical Expert and Patent Solicitor, 177 Times Building, New York City.	Jan. 3, 1889
ROSENBERG, E. M., *M. E.*	Residence, 138 W. 85th St., New York City.	Oct. 21, 1890
ROWLAND, ARTHUR JOHN	Professor of Electrical Engineering, Drexel Institute; residence, 3220 Spencer Terrace, Philadelphia, Pa.	Sept. 19, 1894
ROWLAND, HENRY A.	Professor of Physics, Johns Hopkins University, Baltimore, Md.	Mar. 21, 1894
ROYCE, FRED W.	Electrician and Patent Solicitor, 1410 Pennsylvania Ave., Washington, D. C.	April 15, 1884
RUSHMORE, DAVID B.	Westinghouse Electric and Mfg. Co., Pittsburg; residence, Wilkinsburg, Pa.	Sept. 25, 1895
RUTHERFORD, W. M.	Chief Engineer, Canadian General Electric Co., 65 Front St., W. Toronto, Can.	Sept. 22, 1891
SACHS, JOSEPH	Devising and Consulting Electrical Engineer, 32 Nassau St., New York City.	Mar. 15, 1892
SACKETT, WARD M.	Assistant Chief Draughtsman, Chicago Telephone Co., residence 3739 Ellis Ave., Chicago, Ill.	Oct. 17, 1894
SAGE, HENRY JUDSON	Sage & Co., Electrical Engineers, Rochester, Pa.	Dec. 20, 1893

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Name.	Address.	Date of Election.
SAHULKA, DR. JOHANN	Docent of Electrotechnics, Technische Hochschule, Vienna, Austria	Dec. 20, 1893
SANBORN, FRANCIS N.	Torrington, Conn.	Nov. 24, 1891
SANDERSON, EDWIN N.	With Westinghouse Electric and Mfg. Co., E. Pittsburg, Pa.; residence, 514 Shady Ave., E. Pittsburg, Pa.	Oct. 17, 1894
SAWYER, FRED. W.	68 Mount Vernon St., Fitchburg, Mass.	June 27, 1895
SAXELBY, FREDERICK	Electrical Engineer, 288 Summer Ave., Newark, N. J.	June 5, 1888
SCHEIBLE, ALBERT	Manager for George Cutter, 851 The Rookery, Chicago, Ill.	June 20, 1894
SCHLOSSER, FRED. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 1038 Leffingweil Ave., St. Louis, Mo.	Sept. 22, 1891
SCHOEN, ALLEN MCGEE	Electrician, South Eastern Tariff Association, Fitten Building, Atlanta, Ga.	Sept. 20, 1893
SCHREITER, HEINR, *C. E.*	Counsellor and Attorney, 106 Fulton St, New York City.	Jan. 17, 1893
SCIDMORE, FRANK L.	With Western Electric Co.; residence, 480 Lexington Ave., New York City.	Dec. 18, 1895
SEARING, LEWIS	Shepard & Searing, Mechanical and Electrical Engineers, 842-3 Equitable Building, Denver, Col.	April 3, 1888
SEARLES, A. L.	Engineering Dept., Fort Wayne Electric Corporation, Fort Wayne, Ind.	April 18, 1894
SEE, A. B.	A. B. See Manufacturing Co., 116 Front St.; residence, 107 East 19th St, (Flatbush), Brooklyn, N. Y.	Jan. 17, 1893
SEELY, J. A.	Electrical Engineer and Contractor, 121 Liberty St., New York City.	April 15, 1884
SEITZINGER, HARRY M.	Consulting and Constructing Engineer, 6 Northampton St., Wilkes-Barre, Pa.	Sept. 20, 1893
SERRELL, LEMUEL WM.	Mechanical and Electrical Engineer, 99 Cedar St., New York City; residence, Plainfield, N. J.	Nov. 1, 1887
SEVER, GEORGE F.	Instructor in Electrical Engineering, Columbia College, New York City.	Jan. 17, 1894
SERVA, A. A	With Fort Wayne Electric Corporation, 101 The Bourse, Philadelphia, Pa.	Dec. 20, 1893
SHAIN, CHARLES D.	136 Liberty St., New York City.	June 7, 1892
SHARP, CLAYTON H.	Instructor, Department of Physics, Cornell University, 122 University Ave., Ithaca, N. Y.	May 15, 1894
SHARPE, E. C.	Consulting Electrical Engineer, Riverside, Cal.	Feb. 26, 1896
SHEDD, JOHN C.	Professor of Physics and Applied Electricity, Marietta College; residence, 512 Fourth St., Marietta, Ohio.	Dec. 19, 1894
SHEEHY, ROBERT J.	President, Sheehy Automatic Railroad Signal Co., 122 Pearl St., Boston, Mass.	April 21, 1891

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Name.	Address.	Date of Election.
SHIELDS. W. J.	Consulting Engineer, New Wilmington, Pa.	Sept. 19, 1894
SHOCK, THOS. A. W.	Gen'l Sup't Sacramento Electric Power and Light Co., Sacramento, Cal.	Mar. 20, 1895
SHONNARD, HAROLD W.	Designer of Electrical and Special Machinery; residence, 199 W. 134th St., New York, N. Y.	Oct. 23. 1895
SHRADER, WILLIAM	Professor of Electrical Engineering, University of Missouri. Columbia, Mo.	Sept. 20, 1893
SIMPSON, ALEXANDER B.	Estimator, N. Y. Electrical Equipment Co., N. Y. City; residence, 125 2nd Place, Brooklyn, N. Y.	May 21, 1895
SISE, CHARLES F.	President, Bell Telephone Co., of Canada, P. O. Box 1918, Montreal, Canada.	June 8, 1887
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph Cable Co., New York City; residence, 703 President St., Brooklyn, N. Y.	Sept. 25, 1895
SLADE, ARTHUR J., *Ph.D.*	Engineer, with George Hill, 44 Broadway; residence, 62 East 66th St., New York City.	Sept. 19, 1894
SLATER, FREDERICK R.	Designing Department, Otis Bros. & Co., 153 Warburton Ave., Yonkers, N. Y.	Oct. 17, 1894
SMITH, CHARLES HENRY, JR.	Box 2, Atlanta, Ga.	Jan. 17, 1894
SMITH, FRANK E.	Chief Electrician, Edison Light and Power Co., 229 Stevenson St., San Francisco, Cal.	Sept. 19, 1894
SMITH, FREDERICK H.	Civil Engineer, 216 Equitable Bldg., Baltimore. Md.	Nov. 12, 1889
SMITH, HAROLD BABBITT	Professor of Electrical Engineering, Purdue University, 164 Columbia St., Lafayette, Ind.	Nov. 24, 1891
SMITH, J. BRODIE	Supt. and Electrician. Manchester Electric Light Co., 142 Merrimack St., Manchester, N. H.	Mar. 21, 1894
SMITH, J. ELLIOT	Superintendent Fire Alarm Telegraph, 122 W. 73d St., New York City.	April 15, 1884
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N. J.	May 19, 1891
SMITH, T. JARRARD	Manager Electrical Dept., The E. S. Greeley & Co., 7 Dey St., New York City.	April 19, 1892
SPENCER, THEODORE	With Bell Telephone Co., 406 Market St., Philadelphia, Pa.	Mar. 21, 1893
SPICER, CHAS. W.	[Address Unknown.]	Nov. 12, 1889
SPIKE, CLARENCE J.	Halifax, N. S.	Mar. 18, 1890
SPRAGUE, FRANK J.	(*Past-President.*) Vice-Prest. Sprague Electric Elevator Co.. Postal Telegraph Bldg., 253 Broadway and 182 West End Ave., New York City.	May 24, 1887

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Name.	Address.	Date of Election.
SPROUT, SIDNEY S.	Electrical Engineer, 303 California St., San Francisco, Cal.	Jan. 17, 1894
SPRUSON, WILFRED J.	Member of the firm of Hepburn & Spruson, Consulting Engineers and Electricians, 169 King St, Sydney, N. S. W.	Dec. 16, 1890
SQUIER, GEORGE O., *Ph.D.*	1st Lieut., 3d Artillery, Fortress Monroe, Va.	May 19, 1891
STADELMAN, WM. A.	Agent, Elwell-Parker Co., 26 Cortlandt St., New York City.	Feb. 7, 1890
STAHL, TH.	Creusot Works, Creusot, France.	Nov. 15, 1892
STANLEY, WILLIAM	Electrician, Pittsfield, Mass.	Dec. 6, 1887
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 S. 3d St., Philadelphia, Pa.	Mar. 20, 1895
STEVENS, J. FRANKLIN	Secretary and Treasurer, La Roche Electric Works, American and Diamond Sts.; residence, 1419 Walnut St., Philadelphia, Pa.	Sept. 19, 1894
STINE, WILBUR M.	Director Electrical Dept., Armour Institute, Chicago, Ill.	May 15, 1894
STOCKBRIDGE, GEO. H.	Patent Attorney, Room 114, 39 Cortlandt St, New York City.	May 24, 1887
STOCKLY, GEO. W.	32 Liberty St, New York City; residence, Lakewood, N. J.	April 15, 1884
STONE, CHARLES A.	With Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	May 19, 1891
STONE, JOSEPH P.	Electrical Engineer, General Electric Co.; residence, 213 Liberty Street, Schenectady, N. Y.	Dec. 18, 1895
STORER, NORMAN W.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; residence, Wilkinsburg, Pa.	Dec. 18, 1895
STORRS, PROF. H. A.	Professor of Electrical Engineering, University of Vt., Burlington, Vt.	Mar. 21, 1893
STOTT, HENRY G.	Electrical Engineer, Buffalo Gen'l Electric Co., Buffalo, N. Y.	Sept. 25, 1895
STRATTON, ALEX.	With Crocker-Wheeler Electric Co., N. Y.; residence, 2013 5th Avenue, New York City.	Mar. 20, 1895
STRAUSS, HERMAN A.	Electrical Engineer, Westinghouse Electric and Mfg. Co.; residence, 157 Larimer Ave., East Liberty, Pittsburg, Pa.	Oct. 17, 1894
STRONG, FREDERICK G.	402 Exchange Building, Boston, Mass.	Oct. 27, 1891
STUMP, CLARENCE E.	714 Putnam Ave., Brooklyn, N. Y.	May 17, 1887
STURTEVANT, CHARLES L.	Patent Attorney, Atlantic Building, Washington, D. C.	Dec. 20, 1893
SUMMERS, LELAND L.	Electrical Engineer, 1107 The Rookery, Chicago, Ill.	Feb. 16, 1892
SVENTORZETZKY, CAPT. LOUDOMIR	Military Engineering Academy, St. Petersburg, Russia.	Sept. 20, 1893

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Name.	Address.	Date of Election.
SWENSON, BERNARD VICTOR	Assistant Professor of Electrical Engineering, University of Illinois, Champaign, Ill.	Feb. 27, 1895
SWEET, HENRY N.	Chief of Patent Bureau, Thomson Electric Welding Co., 4 Spruce St, Boston, Mass.	May 20, 1890
SYKES, HENRY H.	Chief Engineer, Bell Telephone Co., of Mo.. Telephone Bldg., St. Louis, Mo.	Oct. 18, 1893
TABER, ROBERT B.	Gas Engineer, Special Agent General Electric Co., 620 Atlantic Ave., Boston, Mass.	Sept. 16, 1890
TAIT, FRANK M.	Superintendent, Catasauqua Electric Light and Power Co., 731 3d St., Catasauqua, Pa.	Sept. 19, 1894
TAPLEY, WALTER H.	Electrician in Government Printing Office, care of Public Printer, Washington, D. C.	Oct. 25, 1892
TEMPLE, WILLIAM CHASE	Mechanical and Electrical Engineer, Lewis Block, P. O. Box 800, Pittsburg, Pa.	May 3, 1887
TESLA, NIKOLA	Electrical Engineer and Inventor, 46 E. Houston St., The Gerlach, 53 W. 27th St., New York City.	June 5, 1888
THOMPSON, WILLIAM GEO. MACNEILL	Resident Engineer, Sault Ste. Marie Canal, St. Catharines, Ont.	July 12, 1887
THORDARSSON, CHESTER H.	Chicago Edison Co.; residence, 284 Rush St., Chicago, Ill.	Dec. 18, 1895
TOBEY, WILLIAM BOARDMAN	General Manager, S. K. C. Specialty Co., Pittsfield, Mass.	Sept. 16, 1890
TOERRING, C., JR.	Electrical Engineer, Helios Electric Co., 1614 Green St., Philadelphia, Pa.	April 18, 1894
TORCHIO, PHILIPPO	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane Street, New York City.	June 27, 1895
TOWER, GEORGE A.	Electrical Engineer, The Sherwood Land Co., and The Jefferson Hotel Co., 109 S. First St., Richmond, Va.	May 15, 1894
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 5 Beekman St., New York City.	July 10, 1888
TREADWELL, AUGUSTUS, JR.	Private Assistant, Polytechnic Institute, 488 3d St., Brooklyn, N. Y.	Feb. 21, 1894
TROTT, A. H. HARDY [Life Member.]	Care Direct U. S. Cable Co., Old State House, Boston, Mass.	Jan. 20, 1891
TUTTLE, GEORGE W.	Electrical Engineer, Sawyer-Man Electric Co., 510 W. 23d St.; residence, 328 W. 23d St., New York City.	Mar. 17, 1891
VAIL, THEO. N.	26 Cortlandt St., New York City.	April 15, 1884
VAN BUREN, GURDON C.	Electrician and Electrical Contractor, 84 Clinton Ave., Albany, N. Y.	Oct. 25, 1892
VANDEGRIFT, JAMES A.	Westinghouse Electric and Mfg. Co., residence, 158 Ridge Ave., Allegheny, Pa.	Nov. 24, 1891

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Name.	Address.	Date of Election.
VANDERSLICE, G. HAMILTON	Armory, Old City Hall, Pittsburg, Pa.	Dec. 19, 1894
VAN VLECK, FRANK	President, Van Vleck Tramway Co., Wells Fargo Bldg., Los Angeles, Cal.	Nov. 16, 1886
VAN WYCK, PHILIP V. R., JR.	981 Madison Ave., New York City.	April 21, 1891
VARLEY, RICHARD, JR.	General Manager, Varley Duplex Magnet Co., 46 East Houston St., New York City.	Mar. 18, 1890
VARLEY, THOMAS W.	[Address Unknown.]	Sept. 19, 1894
VARNEY, WILLIAM WESLEY	Attorney at Law, Electrical Expert, 118 East Lexington St.; residence, 1001 Harlem Ave., Baltimore, Md.	Nov. 21, 1894
VERLEY, HORACE S. L.	With Dr. Wm. E. Geyer, as Laboratory Assistant, Stevens Institute, Hoboken, N. J.; 136 Liberty St., New York City.	May 17, 1892
VOIT, DR. ERNST	Professor of Electricity, Technical University, Schwanthalerstrasse, Munchen, Germany.	Mar. 21, 1894
WACKER, GEORGE G.	1340 Vanderbilt Ave., New York City.	Sept. 6, 1887
WAGNER, EDWARD ANDREWS.	Electrician, The Mexican International R. R. Co., Eagle Pass, Texas	Jan. 22, 1896
WALKER, ARTHUR F.	Sup't and Electrical Engineer, Edison Light Co., Grand Rapids, Mich.	Oct. 23, 1895
WALLACE, GEO. S.	Telegraph Office Manager, Chesapeake & Ohio Ry. Co., Box 214, Huntington, W. Va.	Oct. 25, 1892
WALLACE, WILLIAM	Wire Manufacturer, Ansonia, Conn.	April 15, 1884
WALTER, HENRY E.	[Address Unknown.]	April 2, 1889
WARDELL, GEORGE PHELPS	Secretary, Department of Science and Technology, Pratt Institute, Brooklyn, N. Y.	Nov. 12, 1889
WARDLAW, GEORGE A.	412 East Willow St., Syracuse, N. Y.	Jan. 17, 1894
WARING, RICHARD S.	Standard Underground Cable Co., 61 Westinghouse Bldg., Pittsburg, Pa.	April 15, 1884
WARNER, CHAS. H.	Consulting Electrical Engineer, 50 Broadway, New York City.	Dec. 20, 1893
WARREN, ALDRED K.	Proprietor, A. K. Warren & Co., 465 Greenwich St., New York; residence New Brighton, S. I., N. Y.	Nov. 20, 1895
WASON, CHAS. W.	Electrical Engineer and Purchasing Agent, Cleveland Electric R. R. Co., 1762 Euclid Ave., Cleveland, O.	May 19, 1891
WASON, LEONARD C.	Vice-Prest., The Aberthaw Co., 31 State Street, Boston; residence, 199 Harvard St., Brookline, Mass.	Dec. 20, 1893
WATERS, EDWARD G.	Resident Manager, General Electric Co., 308 Times Bldg., Pittsburg, Pa.	Mar. 18, 1890

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WATSON, ROBERT	Patent Attorney, 931 F. St., N. W., Washington, D. C.	Oct. 21, 1890
WATTS, H. FRANKLIN	Electrical Engineer and Contractor, 5171 Heston St., Philadelphia, Pa.	May 20, 1890
WEAVER, NORMAN R.	Box 87, Selma, Ala.	Oct. 25, 1892
WEBB, HENRY STORRS	Instructor in Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Nov. 20, 1895
WEBSTER, DR. ARTHUR G.	Assistant Professor of Physics, Clark University, 936 Main St., Worcester, Mass.	Jan. 19, 1892
WEBSTER, EDWIN S.	Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	April 21, 1891
WENDLE, GEORGE E.	760 W. 4th St., Williamsport, Pa.	Feb. 21, 1894
WEST, JULIUS HENRIK	Engineer, Handjery St., 58 Friedenau, Berlin, Germany.	Sept. 20, 1893
WELLES, FRANCIS R.	Manufacturer, 46 Avenue de Breteuil, Paris, France.	Sept. 6, 1887
WHARTON, HUGH M.	Electrical Engineer, 69 Christopher St., Montclair, N. J.	May 15, 1894
WHITE, H. C.	Manager, Phœnix Iron Works Co., 208 Ballett Bldg., Philadelphia, Pa.	April 15, 1884
WHITE, J. G.	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway, New York City.	April 2, 1889
WHITE, WILL F.	Electrical Engineer, Vice-President, New Omaha T.-H. Electric Light Co , 309 So. 13th St., Omaha, Neb.	Feb. 7, 1890
WHITMORE, W. G.	Electrical Engineer, General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
WHITNEY, HENRY M. [Life Member.]	81 Milk St., Boston, Mass.	July 12, 1887
WIESE, GUSTAV ADOLPH	City Electrician of Alameda, 718 Haight Ave., Alameda, Cal.	Sept. 25, 1895
WIGHTMAN, MERLE J.	Library Building, Scranton, Pa.	Mar. 5, 1889
WILEY, WALTER S.	Engineer, with the American Waterworks, 1107 No. 40th St.. Omaha, Neb.	April 18, 1894
WILEY, WM. H.	Scientific Expert, 53 E. 10th St., New York City.	Feb. 7, 1888
WILLIAMS, CHARLES JR.	Electrician, 1 Arlington Street, East Somerville, Mass.	April 15, 1884
WILLIAMSON, G. DEWITT	Dobbs Ferry, N. Y.	April 18, 1893
WILSON, CHESTER P.	Chief Engineer, East St. Louis Plant, Swift & Co., 31 Nicholson Place, St. Louis, Mo.	Sep. 25, 1895
WINAND, PAUL A. N.	Engineer and Supt., Schleicher, Schumm & Co., 3200 Arch St., Philadelphia, Pa.	June 20, 1894
WINCHESTER, SAMUEL B.	9 Laurel St., Holyoke, Mass.	May 15 1894

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Name.	Address.	Date of Election.
WINSLOW, I. E.	The General Traction Company, Ltd., 35 Parliament Street, Westminster, London, Eng.	Nov. 12, 1889
WINTRINGHAM, J. P.	Theorist, 36 Pine St , New York City, and 153 Henry St , Brooklyn, N.Y.	May 7, 1889
WIRT, HERBERT C.	Engineer, Supply Department, General Electric Co., Schenectady, N. Y.	June 26, 1891
WOOD, E. J.	Consulting Engineer and Contractor, 243 Broadway, New York City.	July 12, 1887
WOODWARD, FRANCKE L.	Undergraduate in Electrical Engineering, Harvard University, 22 Perkins Hall, Cambridge, Mass.	June 26, 1891
WOOLF, ALBERT E.	Electrician and Inventor, Woolf Electric Disinfecting Co. of N. Y., 66 Broad St., New York City.	Sept. 16, 1890
WORSWICK, A. E.	Electrical Engineer, Mutual Light and Power Co , 26 Commerce St , Montgomery, Ala.	Sept. 20, 1893
WRAY, J. GLEN	Cable Tester, Chicago Telephone Co., 162 Centre St., Chicago, Ill.	Sept. 20, 1893
WYBRO, HARRISON C.	Electrical Engineer, Wybro & Lawrence, Los Angeles, Cal.	Dec. 18, 1895
YARNALL, V. H.	Superintendent of Construction, White-Crosby Co., 29 Broadway, New York City.	May 16, 1893
YOUNG, CHARLES I.	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburg. Pa.	June 27, 1895
ZALINSKI, EDMUND L.	Captain of Artillery, U. S. A., (retired), The Century, 7 West 43d St., New York City.	May 17, 1887
ZIMMERMAN, LAURENCE J.	Electrical Engineer and Inventor, 57 Pennsylvania Ave., Brooklyn, N. Y.	Mar. 21, 1893

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Low, George P., 303 California St.
Medina, F. P., 534 Market St.
Meredith, Wynn, 310 Pine St.
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Ridley, A. E. B., 508 California St.
Smith, F. E., 229 Stevenson St.
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15

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Telluride.—Nunn, Paul N.

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Hartford.
Powell, W. H., 55 Oak St.
Robb, Prof. Wm. L., Trinity College.
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Meriden.—Fuller, F. G.

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Crandall, J. E., 619 14th St., N. W.
Chamberlain, F. H., 2411 P St., N. W.
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Hollerith, H., 1054 31st St.
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Jannus, Frankland, 928-30 F. St.
Mauro, Philip, 620 F. St.
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Reber, Samuel, Signal Corps, U. S. A.
Royce, Fred W., 410 Pennsylvania Ave.
Shea, D. W., Catholic University.
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Tapley, W. H., Gov. Printing Office.
Watson, Robert, 931 F. St., N. W.

21

FLORIDA.

Jacksonville.

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St. Augustine.—Best, A. T.

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Armstrong, C. G., 1400 Auditorium Twr.
Arnold Bion J., 1541 Marquette Blg.
Badt, Lt. Francis B., 1215 Monadnock
Baldwin J. C. T., 203 Washington St.
Barton, Enos M. 227 South Clinton St.
Beames, C. F., Monadnock Bldg.
Boughan, E. L., 20 Roslyn Place.
Brown, C. L., 6422 Drexel Ave,
Comstock, L. K., Monadnock Bldg.
Coster, M., N. Y. Life Ins. Bldg.
Crandall, Chester D., 227 S. Clinton St,
Crawford, L. G., 220 Johnson St.
Croxton, A. L., 7118 Drexel Ave.
Cushing, F. W., 1106 The Rookery.
Cutter, George, 851 The Rookery.
Dommerque, F. J., 203 Washington St.
Dorr, Frank H., Monadnock Block.
Eddy, H. C., Lees Building.
Ellicott, E. B., 227 So. Clinton St.
Etheridge, Locke, 203 Washington St.
Frantzen, Arthur, 353 Dearborn St.
Galletly, J. Fred., Care of Swift & Co.
Gerry, M. H. Jr., 146 Throop St.
Gutmann, L., 410 La Salle Ave.
Haskins, Clark C. 582 W. Congress St.
Hibbard, Angus S. 203 Washington St.
Hornsby, H. H., 16 City Hall.
Insull, Samuel, 513 Rookery.
Izard, E. M., 315 Dearborn St.
Jackson, T. K., Siemens & Halske Co.
Keller, C. L., 5940 East End Ave.
Kreidler, W. A., 510 Marquette Bldg.
Larned, S. J., 203 Washington St.
Malia, J. P., 5314 Union Ave.
Mayer, Geo. M., 79 Fifth Ave.
McMeen, S. G., 1306 Ashland Block.
Munns, C. K., 947 Rookery.
Myers, L. E., 917 Monadnock Bldg.
Neiler, S. G., 1409 Manhattan Bldg.
Nichols, G. P., 1036 Monadnock.
Norton, E. F., 175 Dearborn St.
O'Connell, J. J., 203 Washington St.
Pierce, R. H., 1409 Manhattan Bldg.
Pratt, Chas. A., 39th St. & Stewart Ave.
Rae, F. B., 134 Monroe St
Rhodes, S. A., 203 Washington St.
Richardson, R. E., 1409 Manhattan Bdg
Rodman, Sam'l, Jr., 106 Pullman Bldg.
Thordarsson, C H., 513 Rookery.
Sackett, W. M., 203 Washington St.
Scheible, Albert, 851 The Rookery.
Stine, Prof. W. M., Armour Institute.

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Summers, Leland L., 1107 Rookery.
Wait, Henry H., 4919 Madison Ave.
Warner, E. P., 227 So. Clinton St.
Wilson Charles H., Monadnock Bldg.
Wray, J. G., 162 Centre St.

58

East St. Louis.—Lindsay, W. E.

Highland Park.—Gray, Dr. Elisha

Maywood.—Kammeyer, C. E.

Oak Park.

Bentley, M. H., 221 Scoville Ave.
Nutting, S. E.
Privat, Louis

3

Urbana.—Esty, William.

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INDIANA.

East Chicago.—Flegel, G. C.

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Childs, S. W., Foellinger Block.
Crawford, D. F., P. R. R.
Duncan, Thos., 407 Broadway.
Hadley, A. L., 149 Griffith St.
Hunting, F. S., 330 W Washington St.
MacFadden, C. K., West'n Gas Cons. Co.
Searles, A. L., Ft. Wayne Elec. Cor.

8

Lafayette.

Boggs, L. S.
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Baltimore.

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Burton, W. C., 1425 Maryland Ave.
Duncan, Dr. L., Johns Hopkins Univ.
Hall, Clayton C., 810 Park Ave,
Hering, H. S., 1809 Park Ave.
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McCay, H. K., 106 E. German St.
Morrison, J. Frank, 15 South St.,
O'Sullivan, M. J., B. & O. R. R.
Peirce, Wm. H., Keyser Building.
Ries, E. E., 1919 Druid Hill Ave.
Rowland, Prof. H. A.,
Johns Hopkins University.
Smith, F. H., 216 Equitable Bldg.
Varney, W. W., 118 E. Lexington St.
Young, C. G., 706 Equitable Bldg.

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Reisterstown.—Bauer, W. J.

MASSACHUSETTS.

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Boston.

Adams, A. D., 620 Atlantic Ave.
Almon, G. H., 620 Atlantic Ave.
Archbold, Wm. K., 328 Exchange Bldg.
Ayer, Jas. I. 611 Sears Bldg.
Bell, Louis, 620 Atlantic Ave.
Berthold, V. M., 125 Milk St.
Blake, T. W. 125 Milk St.
Blodgett, Geo. W., B. & A. R. R.
Brophy, Wm., 12 Old Court House.
Bubert, J. F., 402 Exchange Bldg.
Burleigh, Chas B., 620 Atlantic Ave.
Burton, Geo. D., 194 Washington St.
Cabot, F. E. 55 Kilby St.
Chadbourne, H. R., Jr., 130 Bedford St.
Childs, A. E., 333 Exchange Bldg.
Claflin, Adams D., 53 State St.
Coffin, Chas. A., 620 Atlantic Ave.
Colles, G. W., Jr., 118 Charles St.
Corey, Fred. B., 150 Devonshire St.
Craig, J. Hally, 49 Federal St.
Crosby, J. W., 38 Bedford St.
Cross, Prof. Chas. R., Institute Tech.
Cumner, A. B., 69 Broad St.
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deKhotinsky, Capt. A.,
42 Farnsworth St.
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Doolittle, Thos. B., 125 Milk St.
Edgar, C. L. 3 Head Place.
Erickson, F. Wm., 3 Head Place.
Farnham, I. H., 125 Milk Street.
Ford, Wm. S., Room 73, 125 Milk St.
Garratt, A. V., 61 Hampshire St.
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Hudson, John E., 125 Milk St.
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Paine, Sidney B., 180 Summer St.
Parcelle, Albert L., 157 Washington St.
Puffer, Wm. L., Mass. Inst. of Tech.
Robinson, D. P., 4 P. O. Square.
Robb, Russell, 4 P. O. Square.
Sheehy, R. J., 122 Pearl St.
Stearns, C. K., Kneeland St. Station.
Stone, Charles A., 4 P. O. Square.
Strong, F. G., 402 Exchange Bldg.
Sweet, Henry N., 4 Spruce St.
Trott, A. H. H., Old State House.
Taber, Robert B., 620 Atlantic Ave.
Wason, L. C., 31 State St.
Webster, Edwin S., 4 P. O. Square.
Weller H. W., 33 Equitable Bldg.
Whitney, Henry M., 81 Milk St.
58

Brookline.

Bliss, D. M., 1 Davis Ct., Washington St.
Lee, J. C., Mountfort St. Longwood.
2

Cambridge.

Adams, C. A. Jr., 13 Farrar St.
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Lynn.

Boyer, E. E., Gen'l Electric Co.
Ekstrom, Axel, 92 Hamilton Ave.
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Lemp, H. Jr., Thomson Elec. Weld Co.
Thomson, Elihu, General Electric Co.
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Marlborough.—Bottomley, Harry.

Pittsfield.

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Tobey, W. B., Dawes Ave. & High St.
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Webster, Dr. A. G., 936 Main St.
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MICHIGAN.

Ann Arbor.—Carhart, H. S.

Calumet.—Bosson, Fred. N.

Detroit.

Blades, Harry H., 1343-55 Cass Ave.
Dow, Alex, 411 Hammond Bldg.
Smith, Jesse M., 36 Moffatt Block.
Wilkes, G., 816 Chamber Commerce.
4

Grand Rapids.—Walker, A. F.

Ishpeming.—Mills, Frank P.

MINNESOTA.

Minneapolis.

Brooks, Morgan, 249 Second Ave., So.
Shepardson, G. D., Univ. of Minn.
2

St. Paul.—Byllesby, Henry M.

MISSOURI.

Columbia.—Shrader, Prof. Wm.

Kansas City.

Blood, W. H., Jr. 535 Delaware St.
Casper, Louis, Box 257.
Weeks, E. R., National Bank of Kansas City Building.
3

St. Louis.

Durant, Geo. F., 511 No. 4th St.
Garrels, W. L., 4531 West Pine Bouv.
Iijima, Zentaro, 2017 Lucas Place.
Morse, Geo. H., Wagner Elec. Mfg. Co.
Randall, J. E., 1912 Olive St.
Reinmann, A. L., 2011 Pine St.
Schlosser, F. G., 1038 Leffingwell Ave.
Sykes, H. H., Telephone Bldg.
8

MONTANA.

Great Falls.—Morrow, John T.

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NEBRASKA.

Lincoln.—Owens, Prof. R. B.

Omaha.

Lane, Vance
White, W. F., 309 So. 13th St.
Wiley, W. S., 1107 N. 40th St.

3

NEVADA.

Virginia City.—Fielding, Frank E.

NEW HAMPSHIRE.

Hanover.—Crehore, Dr. A. C.

Manchester.

Clough, A. L., Box 114.
Smith, J. Brodie, 142 Merrimack St.

2

Portsmouth.—Flanagan, T. F.

NEW JERSEY.

Bayonne City.

Bennett, E. H., Jr., 17 E. 33d St.
Fleming, Wilfrid H., 70 W. 3d St.

2

Bloomfield, N. J.—Carichoff, E. R.

Bridgeton.—Smith, Oberlin.

Bound Brook.—Loomis, O. P.

Camden.—Harrington, Walter E.

East Orange.

Dunn, Gano S., Ampere.
Jackson, F. E., 61 So. Grove St.
Leonard, H. Ward.

3

Elizabeth.—Diehl, Philip.

Harrison.

Eyre, M. K.
Howell, Wilson S.
Marshall, J. T.
Page, A. D.

4

Hoboken

Cuntz, Johannes H., 325 Hudson St.
Denton, Prof. J. E., Stevens Institute.
Geyer, Dr. Wm. E., " "
Morton, Dr. H., Stevens Institute.
Verley, Horace S. L., " "

5

Jersey City,—Ockershausen, H. A.

Maywood.—Jaeger, Chas. L.

Montclair.

Harrison, Harold
Wharton, H. M., 69 Christopher St.

2

Newark.

Anthony, Watson G., 32½ Webster St.
Atwood, Geo. F.,
Mechanic and Lawrence Sts.
Bosch, Adam, Fire Alarm Telegraph.
Colby, Edward A., Lock Box 313.
Criggal, J. E., 138 Bloomfield Ave.
Doane, S. Everett, 68 Park Place.
Heinrich, Richard O., 114 William St.
Howell, J. W., 761 High St.
Martin, J., 16 Oak St.
Moore, D. McF., 52 Lawrence St.
Uebelacker, C. F., 30 N. 11th St.
Weston, Edward, 114 William St.

12

Orange.—Edison, Thomas A.

Passaic.

Alden, James S., 486 River Drive.
Mott, S. D.

2

Plainfield.

McClurg, W. A., 207 Madison Ave.

Princeton.—Brackett, Prof. C. F.

Rahway.—Buys, Albert.

Roselle.—Lawton, W. C.

Rutherford.—Petty, Walter M.

Trenton.

Elmer, Wm., Jr.
Roebling, Ferdinand W.

2

South Orange.—Delany, P. B.

Westfield.—Foote, Thos. H.

NEW MEXICO.

Mesilla Park.—Brady, F. W.

NEW YORK.

Albany.

Du Bois, Julian, N. Y. C. & H. R. R. R.
McElroy, James F., 131 Lake Ave.,
Miller, Wm. C., 3 South Hawk St.,
Van Buren, Gurdon C., 84 Clinton Ave.

4

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Auburn.—Case, W. E., 196 Genesee St.

Bedford.—Luquer, T. T. P.

Belmont.—Gorton, Charles.

Brooklyn.

Andrews, W. C., 162 Hicks St.
Barstow, W. S., 360 Pearl St.
Berresford, A. W., 197 Van Buren St.
Broich, Jos., 448 8th Ave.,
Chinnock, C. E., 137 Sixth Ave.,
Gerry, J. H., 163 Grand Ave.
Graham, G. W., 741 Marcy Ave.
Halsey, W. B., 246 Elton St.
Henderson, H. B., 689 Willoughby Ave.
Hochhausen, Wm., 76 Hanson Place.
Knudson, A, A., 688A Greene Ave.
Mason, James H., 10 Fifth Ave.
McBride, James, 146 Kent St.,
Mosscrop, W. A., 189 Montague St.
Ormsbee, A. F., 183 Joralemon St.
Parker, Herschel C., 21 Fort Green Pl.
Prince, J. Floyd, 868 Flatbush Ave.
Proctor, T. L., 45 York St.
Reilly, John C., 16 Smith St.,
Riker, A. L., 45 York St.
Robinson, F. G., 156 Macon St.
Roller, Lieut. J. E., 515 Clinton Ave.
Sargent, W. D., 16 Smith St.,
See, A. B., 116 Front St.
Sheldon, Dr. Samuel, 170 State St..
Simpson, A. C., 125 2d Place.
Stump, C. E., 714 Putnam Ave.
Treadwell, Augustus, Jr., 488 3d St.
Wardell, G. P., Pratt Institute.
Zimmerman, L. J., 57 Penna. Ave.
30

Buffalo.

Foster, H. A., 134 Swan St.
Frenyear, T. C. Erie Co. Bank Bldg.
Haskins, C. H., 70 Linwood Ave.
Huntley, C. R., 40 Court St.
Perkins, Frank C., 774 Prospect Ave.
Plumb, Chas., 89 Erie St.
Ricker, C. W., 184 Cleveland Ave.
Stott, H. G., General Electric Co.
8

Canastota — Marvin, H. N.

Cortland.—Dunston, R. E.

Croton on-Hudson.—Knox, F. H.

Dobbs Ferry.—Williamson, G. D. W.

Elmira.

Cahoon, J. B., 217 West 1st St.
Cheney, F. A., Maple Ave.
Wolverton, B. C., N. Y. & Pa. T. & T. Co.,
3

Greenbush.—Pratt Robert J.

Hempstead.—Powell, P. H.

Herkimer.—Lyman, C. W.

Ithaca.

Bedell, Fred. Dr., 117 E. Buffalo St.
Bergholtz, H., Ithaca Street Ry. Co.
Matthews, Chas. P., Locust Grove.
Merritt, Prof. Ernest. Cornell University.
Nichols, Dr. E. L., Cornell University.
Phisterer, F. W. 84 Heustis St.
Ryan, Prof. H. J., Cornell University.
Sharp, Clayton H., 122 Univ. Ave.
8

Jamaica.—Fleming, R.

Jamestown.—Gifford, C. E.

Long Island City.—Shepard, W. E.

Mamaroneck —Farnsworth, A. J.

Newburgh.—Hewitt, C. E.

New York City.

Agnew, C. R., 150 Nassau St.
Albright, H. F., 22 Thames St.
Alexander, Harry, 126 Liberty St.
Alexander, P. H., 45 Broadway.
Anthony, W. A., 5 Beekman St.
Archer, Geo. F., 31 Burling Slip.
Ashley, F. M., 136 Liberty St.
Auerbacher, L. J., 136 Liberty St.
Austin, S. B., 55 Franklin St.
Badeau, I. F., 18 Cortland St.
Baillard, E. V., 106 Liberty St.
Barberie, E. T., 159 W. 66th St.
Bartlett, Edw. E., 23 Rose St.
Batchelor, C., 33 West Twenty-fifth St.
Bates, J. H., 126 Liberty St.
Benjamin, Park, 203 Broadway.
Bennett, J. C., 44 Broad St.
Bethell, U. N., 18 Cortlandt St.
Bijur, Jos., 34 Nassau St.
Binney, Harold, 38 Park Row.
Birdsall, E. T., 18 Broadway.
Bishop, James D., 234 W. 29th St.
Blake, Henry W., 26 Cortlandt St.
Bliss, W. L., 4 Irving Place.
Blizard, Chas., 66 Broadway.
Bogart, A. Livingston, 22 Union Sq.
Bogue, Chas. J., 206 Centre St.
Bohm, Ludwig K., 117 Nassau St.
Bourne, Frank, 39 Cortlandt St.
Brenner, W. H., E. 86th St.
Brixey, W. R., 203 Broadway.
Broadnax, F., 362 W. Broadway.
Brown, Alfred S., 195 Broadway.
Brown, E. D., 18 Cortlandt St.
Brown, J. Stanford, 1 Broadway.
Buckingham, Chas. L., 195 Broadway.
Bunce, Theo. D., Jr., 239 E. 27th St.
Burnett, Douglass, 55 Duane St.
Burke, Jas., 203 Broadway.
Burton, Paul G., 22 Thames St.

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New York City.—Continued.

Caldwell, Edw., 1320 Havemeyer Bldg.
Callender, Romaine, Decker Bldg.
Canfield, M. E., 404 W. 44th St.
Carson, David I., 26 Cortlandt St.
Carty, J. J., 18 Cortlandt St.
Chamberlain, J. C., 1 W. 81st St.
Chandler, Prof. C. F., 41 E. 49th St.
Chase, H. S., 39 Cortlandt St.
Clark, Ernest P., 478 Pearl St.
Clark, Le Roy, Jr., 229 W. 28th St.
Clarke, Charles L., 55 Liberty St.
Coho H. B., 203 Broadway.
Colgate, Geo. L., 136 Liberty St.
Collett, S. D., 18 Cortlandt St.
Colvin, F. R., 203 Broadway.
Compton, A. G., 17 Lexington Ave.
Cothren, W. H., 51 W. 37th St.
Cox, E. V., 50 E. 31st St.
Craigin, Henry A., 120 Broadway.
Crane, W. F. D. 87 Maiden Lane.
Crocker, Francis B., 41 E. 49th St.
Crosby, O. T., 29 Broadway.
Curtis, C. G., Box 412.
Cuttriss, Chas., 1 Broad St.
Dana, R. K., 16 Cliff St
Davenport, C. G., 44 Broad St.
Davidson, E. C., 179 Times Bldg.
Davis, Charles H., 99 Cedar St.
Davis Joseph P., 113 W. 38th St.
Davis, Minor M., 253 Broadway.
Decker, E. P., 18 Cortlandt St.
Denison, S. P., 143 Centre St.
Dey, Harry E., 108 Fulton St.
Dickerson, E. N., 253 Broadway.
d'Infreville, Georges, 10 Desbrosses St
Doremus, Dr. C. A. 59 W. 51st St.
Dressler, Chas. E., 17 Lexington Ave.
Dunbar, F. W., 417 W. 23d St.
Durant, Edward, 39 Cortlandt St.
Dyer, F. M., 10 W. 23d St
Dyer, R. N., 36 Wall St.
Eidlitz, C. L., 10 W. 23d St.
Emery, Dr. Charles E., 95 Nassau St.
Emmet, H. L. R., 36 Cortlandt St.
Ende, S. H., 148 E. 84th St.
Essick, S. V., 53 Park Place.
Etheridge, E. L., 143 Liberty St.
Fay, Thomas J., 143 Liberty St.
Field, C. J., 39 Cortlandt St.
Fiske, Henry G., 45 E. 22nd St.
Flack, J. Day, 1010 Havemeyer Bldg.
Foote, Allen R., 1144 Broadway.
Forbes, Francis, 32 Nassau St.
Freedman, Wm. H., 136 Liberty St.
Frey, C. P., 5 and 7 Dey St.
Frost, J. W., 335 Broadway.
Gale, H. B., 12 West 31st St.
Gallaher, E. B., 99 Cedar St.
Gardanier, George W., 195 Broadway.
Gherardi, B., Jr. 18 Cortlandt St.
Giles, W. A., 29 Cortlandt St.
Gladstone, J. W., 110 E. 23d St.
Goldmark, Chas J. 49 Liberty St.

New York City.—Continued.

Gordon, Reginald, 339 Lexington Ave.
Gott, C. P., Grand Central Palace.
Guy, Geo. H., 203 Broadway.
Hadaway, W. S., Jr., 107 Liberty St.
Hadley, W. B., 30 Cortlandt St.
Hall, Edward J., 18 Cortlandt St.
Hall, William P., 80 Broadway.
Hamblet, James, 195 Broadway.
Hamilton, Geo. A., 22 Thames St.
Hammer, W. J., 1305 Havemeyer Bldg.
Harding, H. McL., 253 Broadway.
Hatzel, J. C., 114 Fifth Ave.
Haviland, F. L., 19 Beekman St.
Hayes, Harry E., 153 Cedar St.
Hedenberg, W. L., 108 Fulton St.
Herzog, Dr. F. Benedict, 55 Broadway.
Higgins, Edward E., 26 Cortlandt St.
Hill, George, 44 Broadway.
Hiss, Wm. J., Jr. 18 Cortlandt St.
Hix, E. R., 41 Wall St.
Holmes, Franklin S., 108 Fulton St.
Holt, M. B., 287 Lexington Ave.
Howson, Hubert, 38 Park Row.
Hubbard, Wm. C., 73 Watts St.
Hubbard, A. S., 126 Liberty St.
Hunt, A. L., 203 Broadway.
Hutchinson, Dr. Cary T., 253 B'way.
Idell, Frank E., 616 Havemeyer Bldg.
Jehl, F., 60 Liberty St.
Jenks, W. J. 44 Broad St.
Jones, Francis W., 253 Broadway.
Johnston, W. J., 253 Broadway.
Keefer E. S., 22 Thames St.
Ker, W. W., 36 Stuyvesant St.
Kinsman, F. E., 66 Broadway.
Kirkegaard, J. G., 106 Fulton St.
Knowles, E. R., 362 W. Broadway.
Knox, James M., 32 W. 129th St.
Lamb, Richard, 1 Broadway.
Langton, John, 29 Broadway.
Lanman, Wm. H., 44 Broad St.
La Roche, F. A., 572 1st Ave.
Ledoux, A. R., 9 Cliff St.
Leslie, E. A., 80th St. and Ave. B.
Lester, W. B., 195 Broadway.
Levy, Arthur B., 810 Lexington Ave.
Lieb, J. W., Jr., 55 Duane St.
Lloyd, Robert McA., 27 Pine St.
Loewenherz, H., 18 Cortlandt St.
Lozier, R. T. E., 150 Nassau St.
Ludlam, H. W., 22 Thames St.
Lufkin, Harvey L., 39 Cortlandt St.
Lundell, Robert, 527 W. 34d St.
MacCulloch, R. C. 209 W. 81st St.
Mackie, C. P., 44 Broad St.
MacQuesten, W. D., 15 Cortlandt St.
Madden, O. E., 41 Wall St.
Mailloux, C. O., 150 Nassau St.
Mansfield, A. N., 153 Cedar St.
Marks, L. B., 51 E. 67 St.
Martin, A. J., 121 Liberty St.
Martin, F., Madison Square Garden.
Martin, T. Commerford, 203 Broadway.

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New York City.—Continued.

Maver, William, Jr., 31 Nassau St.
Mayer, M. M., 411 107th St., E. R.
Mayrhofer, J. C., 165 W. 82d St
McCarthy, L. A., 195 Broadway.
McKibbin, George N., 80 Broadway.
Merrill, E. A., 26 Cortlandt St.
Metcalfe, George R., 136 Liberty St.
Meyer, Julius, 44 Broad St.
Miner, W. M., 26 Cortlandt St.
Monell, Joseph T., 236 W. 22d St.
Mora, M. L., 63 W. 70th St.
Morley, E. L., 114 5th Ave.
Moses, Dr. Otto A., 1037 Fifth Ave.
Moses, P. R., 253 Broadway.
Noll, Augustus, 8 E. 17th St.
Olan, Theo J. W., 65 W. 49th St.
Osterberg, Max, 27 Thames St.
Parmly, C. Howard, 344 W. 29th St.
Parsell, H. V, Jr, 31 E. 21st St.
Pattison, Frank A., 136 Liberty St.
Pearson, F. S., 621 Broadway.
Peck, E. F., 15 Cortlandt St.
Pedersen, F. M., 327 W. 34th St.
Perry, N. W., 6 Park Place.
Pfund, Rich'd, Room 70, 195 Broadway.
Pickernell, F. A., 153 Cedar St.
Poole, Cecil P., 253 Broadway.
Pope, Ralph W., 26 Cortlandt St.
Price, C. W., 13 Park Row.
Pupin, Dr. Michael I., Columbia Coll'ge.
Read, Robert H., 39 Cortlandt St.
Reckenzaun, F., 44 Pine St.
Reed, H. A., 420 E. 25th St.
Reed, H. D., 420 E. 25th St.
Reid, E. S., 17 Times Bldg.
Rennard, J. C., 136 Liberty St.
Rittenhouse, C. T., 253 Broadway.
Roberson, O. R., 195 Broadway.
Roller, F. W., 203 Broadway.
Rouquette, W. F. B., 47 Dey St
Rosenbaum, Wm. A., Times Building.
Rosenberg, E. M., 138 W 85 St.
Sachs, Joseph, 32 Nassau St
Saxelby, Fred'k., 136 Liberty St.
Scheffler, F. A., 126 Liberty St.
Schreiter, Heinr. 106 Fulton St.
Scidmore, F. L., 22 Thames St.
Seely, J. A., 121 Liberty St.
Serrell, Lemuel Wm., 99 Cedar St.
Sever, Geo. F., 41 E. 49th St.
Shain, Charles D., 136 Liberty St.
Shonnard, H. W., 199 W. 134th St.
Sinclair, H. A., 14 Whitehall St.
Skirrow, J. F., 253 Broadway.
Slade, A. J., 62 E. 66th St.
Smith, J Elliot, 122 W. 73rd St.
Smith, T. Jarrard, 7 Dey St.
Spaulding, H. C., 93 Liberty St.
Sprague, Frank J., 253 Broadway.
Stadelman, W. A., 26 Cortlandt St.
Stieringer, Luther, 68 Broad St.
Stockbridge, Geo. H., 39 Cortlandt St.
Stockley, G. W., 32 Nassau St.

New York City.—Continued.

Stratton, Alex., 2013 Fifth Ave.
Taltavall, Thos R, 253 Broadway.
Terry, Chas. A., 120 Broadway.
Tesla, Nikola, 46 E. Houston St.
Thompson, Edward P., 5 Beekman St.
Torchio, P., 53 Duane St.
Townsend, Henry C., 5 Beekman St.
Turner, Wm. S., 47 Times Building.
Tuttle, George W., 510 W. 23rd St.
Vail, J. H., 39 Cortlandt St.
Vail, Theo. N., 26 Cortlandt St.
Vansize, William B., 253 Broadway.
Van Wyck, P. V. R. Jr., 981 Madison Av.
Varley, Richard, Jr., 46 E. Houston St.
Wacker, Geo. G, 1340 Vanderbilt Ave.
Waddell, Montgomery, 29 Broadway.
Warner, Chas. H., 50 Broadway.
Warren, A. K., 465 Greenwich St.
Waterman, F. N., 120 Broadway.
Weaver, W. D., 253 Broadway.
Webb, Herbert Laws, 18 Cortlandt St.
Wetzler, Joseph, 203 Broadway.
Wheeler, S. S., 39 Cortlandt St.
White, J. G, 29 Broadway.
Whitmore, W. G., 44 Broad St.
Wiley, Wm. H., 53 East 10th St.
Wilson, Fremont, 66 Maiden Lane.
Wintringham, J. P., 36 Pine St
Wolcott, Townsend, 1002 Bennett Bldg.
Wood, E. J., 243 Broadway.
Woodbridge J. L., 47 Times Building.
Woolf, Albert E., 66 Broad St.
Yarnall, V. H., 29 Broadway.
Zalinski, Capt. E. L., 7 W. 43d St.

265

Official Stenographer.

Ryan, R. W., 15 E. 99th St.

Niagara Falls.

Lincoln, P. M., Cataract Const. Co.
Price, E. F., Carbide Mfg. Co.
Roper, D. W., Niag. Falls Power Co.

3

Oswego.—Judson, Wm. Pierson.

Ovid.—Waring, John

Pelham Manor.—Gilliland, E. T.

Rhinecliff.—Philbrick, B. W.

Rochester.

de Lancey, D.
Chism, G. F., 90 Exch. Pl. Bldg.
Redman, G. A.

3

Schenectady.

Andrews, W. S., General Electric Co.
Berg, E. J., 53 Washington Ave.
Berg, Eskil, General Electric Co.
Blood, J. B., " " "
Boyles, T. D., " " "
Buck, H. W., 12 N. Church St.
Coles, E. P., General Electric Co.

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Schenectady.—Continued.

Churchill, Arthur, 5 So. Church St.
Davis, W. J., Jr., General Electric Co.
Emmet, W. L. R., " " "
Ely, W. G., Jr 72 Washington Ave.
Fiske, J. P. B., General Electric Co.
Greene, S. Dana, " " "
Griffin, E , " " "
Hakonson. C. H., " " "
Hewlett, Edw. M., " " "
Hobart, H. M., " " "
Kellogg, J. W., " " "
Kirkland, J. W., " " "
Lovejoy, J. R. " " "
Lyman, Jas., 1 North College St.
Merrill, J. L., General Electric Co.
Middlemiss, P. R., Hotel Germania.
Mosman, C. T., General Electric Co.
Oudin, M., " " "
Potter, W. B. " " "
Reid, Thorburn, " " "
Reist, H. G., " " "
Rice E. Wilbur, Jr., " " "
Rohrer, Albert L., " " "
Stebbins, Theodore " " "
Steinmetz, C. P., " " "
Stone, J. P., " " "
Wiener, A. E., 208 Liberty St.
Wirt, H. C., 842 Union St.

35

Seneca Falls.—Wilcox, Norman T.

Syracuse.

Brady, Paul T.
Land, Frank, care of Globe Hotel.
Noxon, C. P. L., 504 Townsend St.
Wardlaw, Geo. A., 412 E. Willow St.

4

Tarrytown.—Liebig, G. A. Jr.

Troy.

Bernard, Edgar G., 43 4th St.
Parks, C. Wellman, 1825 Fifth Ave.

2

Utica.—Nicholson, W. W.

Waterloo.—Mercer, A. G.

Yonkers.

Ihlder, John D
Slater, F. R.

2

NORTH CAROLINA.

Wilmington.—Barnard, J. H.

OHIO.

Akron.—Shaw, E. C.

Cincinnati.

Cabot, John A., 115 West 8th St.
Creaghead, Thos. J., 296 Plum St.
French, Prof. Thos., Jr., Avondale.
Lilley, L. G., Cor. 3d and Walnut.
Gray, W. N., 200 Neave Building.

Cincinnati.—Continued.

Roberts, W. H., 15 Harrison St.
Rodgers, H. S., 264 W. 4th St.

7

Cleveland.

Baylis, R. N., Walker Mfg. Co.
Black, Chas. N., Belden St.
Brush, Chas F., 453 The Arcade
Canfield, Milton C., 18 Clinton St.
Cleveland, W. B.
Cowles, Alfred H., 361 Arcade.
McKinstry, J. P., 316 Seneca St.
Roberts, E. P., Brainard Block.
Sperry, E. A., Mason and Belden Sts.
Wason, Chas. W., 1762 Euclid Ave.

10

Columbus.

Caldwell, F. C., State University.
Thomas, Prof. B. F., State University.

2

Hamilton.

Cornell, Chas. L.
Cornell, J. B.

2

Marietta.—Shedd, J. C.

Salem.—Davis, Delamore L.

Steubenville.—Flood, J. F.

OREGON.

Portland.

Cheney, W. C., Portland G. E. Co.
Coolidge, C. A., 591 Hood St.
Malcolm, P. S., 131 Sixth Ave.
Mitchell, Sidney Z., Fleischner B'ld'g.

4

Salem.—Anson, F. R.

PENNSYLVANIA.

Allegheny City.

Fessenden, Prof. R. A.

Altoona.

Dudley, C. B.
Healy, L. W.

2

Apollo.—Pinkerton, A.

Catasauqua.—Tait, F. M.

Chester.—Arnold, C. R.

Duquesne.—Friedlaender, E.

Erie.—Boynton, E. C.

Germantown.

Condict, G. Herbert, 5328 Green St.
Wirt, Charles. 5104 Newhall St.

2

McKeesport.—Upton, F. R.

Monongahela City.—Acheson, E. G.

Munhall.—Maccoun, E.

New Wilmington—Shields, W. J.

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Phœnixville.—Perot, L. Knowles.

Philadelphia.

Billberg, C. O. C., 3200 Arch St.
Braddell, Alfred E., 316 Walnut St.
Bragg, Chas. A., 302 Girard Bldg.
Darlington, F. W., 907 Drexel Bldg.
Drysdale, W. A., Hale Bldg.
Eglin, W. C. L., 909 Walnut St.
Entz, J. B., 19th St. and Allegheny Ave.
Flagg, S. G., Jr., 19th St. and Penn. Ave.
Gerson, L. J., 804 Walnut St.
Gharky, W. D., 820 Dauphin St.
Glading, F. W., 2005 E. York St.
Griscom, W. W., 224 Chestnut St.
Grist, J. E. 50th St. & Lancaster Ave.
Hering, Carl, 927 Chestnut St.
Hewitt, Chas., 920 Spruce St.
Houston, Dr. E. J., 1105 Betz Bldg.
Hunter, Rudolph M., 926 Walnut St.
Ives, Lieut. E. B., 917 Betz Bldg.
Keller, E. R., 711 Reading Terminal.
Kennelly, A. E., 1106 Betz Bldg.
Levis, Minford, 54 North 4th St.
Lloyd, Herbert, Drexel Bldg.
Lloyd, J. E. 2008 N. 18th St.
Marks, Prof. W. D., Edison Elec. Lt. Co.
Patton, P. I., 1026 Filbert St,
Pike, C. W., 711 Reading Terminal.
Reed, C. J., 3313 N. 16th St
Rowland, Prof. A. J., Drexel Inst.
Serva, A. A., 101 Bourse Bldg.
Sheble, F., 1026 Filbert St.
Smith, T. Carpenter, 212 Drexel Bldg.
Spencer, Theo., 406 Market St.
Stanton, C. H. 1517 Walnut St.
Stevens, J. F., 1419 Walnut St.
Toerrring C. Jr., 1614 Green St.
Uhlenhaut, F., Jr., 4101 Haverford St.
Watts, H. F., 5171 Heston St.
White, H. C., 208 Ballitt Bldg.
Willyoung, E. G., 711 Reading Term.
Wilson, C. P., 843 N. 41st St.
Winand, P. A. N., 3200 Arch St.
Wright, Peter, Drexel Bldg.,

42

Pittsburg

Blaxter, G. H., Westinghouse Bldg.
Bliss, Geo. S., Telephone Bldg.
Dunlap, W. K., West'house E. & M. Co.
Eden, M. E., 83 Fourth Ave.
Fisher, H. W., Standard Und. Cable.
Floy, Henry, Westinghouse E. & M. Co.
Frost, F. R., " " "
Hartwell, Arthur, " " "
Huguet, Chas. K. West'house E. & M. Co.
Hutchinson, F. L. " " "
Ingold, Eugene, 1669 Second Ave.
Keller, E. E., 222 Murtland Ave.
Lange, Philip A., West'house E. & M. Co.
Le Pontois, Leon. " " "
Mershon. R. D., " " "
Myers, Geo. Francis, Penn Building.

Pittsburg.—Continued.

Osborne, L. A., West'house E. & M. Co.
Phillips, Leo A. " " "
Requier, A. M., " " "
Rushmore, D. B. " " "
Sanderson, E. N., " " "
Schmid, A., " " "
Scott, Chas. F., " " "
Smith, F. S., " " "
Stillwell L. B., " " "
Storer, N. W., " " "
Strauss, Herman A. " " "
Temple, William Chase, P. O. Box 800.
Vandegrift, Jas. A., Westinghouse Co.
Vanderslice, G. H.,
Penn Ave. near 4th St.
Waring, R. S., 61 Westinghouse Bldg.
Waters, Edward G., 308 Times Bldg.
Winslow, G. H., 700 Lewis Block.
Wurts, A. J., Westinghouse E. & M. Co.
Young, C. I. " " " "

35

Rochester.

Sage, H. J.
Shallenberger, O. B.

2

Scranton.

Donner, W. H.
Wightman, Merle J.

2

South Bethlehem.

Klinck, J. Henry
Macfarlane, Alexander.
Webb, H. S.,

3

State College.

Jackson, Prof. J. P.
Lardner, H. A,

2

West Bethlehem.—Lattig, J. W.

Wilkes-Barre.

Bates, M. E.
Harvey, R. R., 10 S. Franklin St.
Seitzinger, H. M.

3

Williamsport.—Wendle, G. E.

Winterburn.—Blanchard, C. M.

RHODE ISLAND.

Providence.

Henshaw, F. V., 86 Weybosset St.
Lenz, Chas. O., 510 Ind. Trust Bldg.
Miller, Joseph A., 25 Butler Exchange.
Phillips, Eugene F., Phillipsdale.

4

SOUTH CAROLINA.

Charleston.—Burt, B. T.

TENNESSEE.

Memphis.—Roessler, Capt. S. W.

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TEXAS.

Austin.—McRae, Prof. A. L.

Dallas.—Mottram, W. T. M.

Eagle Pass.—Wagner, E. A.

UTAH.

Salt Lake City.—McKay, C. R.,

VERMONT.

Brattleboro.

Childs, W. H.
Fuller, Hon. Levi K.

2

Burlington.—Storrs, Prof. H. A.

Rutland.

Francisco, M. J.
Larrabee, R. N.

2

VIRGINIA.

Blacksburg.—Randolph, L. S.

Fortress Monroe.—Squier, L't G.O.

Norfolk.—Crews, J. W.

Richmond

Johnston, A. L., 1112 E. Main St.
Leonard, M.B., Sup't C. & O. R.R. Tel.
McCluer, C. E., So. Bell T. & T. Co.
Tower, Geo. A., 109 S. First St.
Trafford, E. W., Foot 7th St.

5

WASHINGTON.

Everett.

Butler, William C.
Kay, Wm. D.

2

Tacoma.—Dame, F. L.

WEST VIRGINIA.

Huntington.—Wallace, G. S. Box 214

Morgantown.—Aldrich, William S.

Wheeling.—Sands, H. S.

WISCONSIN.

Madison.

Davies, John E., 523 Carroll St.
Fortenbaugh, S B.
Jackson, Dugald C.
Jones, F. R., University of Wis.

4

Milwaukee.

Boardman, H. B.
Mann, R. B., 643 Franklin St.

2

DOMINION OF CANADA.

NOVA SCOTIA.

Halifax.

Cogswell, A. R., 34 Bishop St,
Spike, Clarence J.

2

Hazel Hill.

Colley, Benjamin W.
Dickenson, Samuel S.

2

New Glasgow.—Bowman, Fred. A.

ONTARIO.

Berlin.—Breithaupt, E. Carl

Ottawa.

Ahearn, T.
Dion, Alfred A., 72 Sparks St.

2

Peterborough.

Hartman, Herbert T.
Stephens, Geo.

2

Rat Portage.—McCrossan, J. A.

St. Catharines.

Thompson, William G. M.

Toronto.

Rosebrugh, Thomas R.
Ross Norman, 65 Front St.
Rutherford, W. M., 63 Front St
White Fraser, Geo., 28 Toronto St.

4

QUEBEC.

Montreal.

Carus-Wilson, Prof. C. A.
Gossler, P. G., 94 Queen St.
Ross, Robert A, 94 Queen St.
Sise, Charles F., P. O. Box 1918,

4

MEXICO.

City of Mexico.—Peck, S. C.

CENTRAL AMERICA.

GUATEMALA.

Quezaltenango.—Morehouse, H. H.

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SOUTH AMERICA.

ARGENTINA.

Buenos Aires.—McCrosky, J. W.

UNITED STATES of BRAZIL.

Para.

Chermont, A. L., Box 252.
da Cunha, Manoel Ignacio,
Empresa Industrial Gram Para.
2

Rio Janeiro.

Degen, Lewis
Mitchell, James
2

CHILI.

Santiago.—Jones, G. H.

WEST INDIES.

JAMAICA.

Kingston.—Wilson, Harry C.

AFRICA.

CAPE OF GOOD HOPE.

Cape Town.—Standford, William.

ASIA.

JAPAN.

Nakanoshima.—Iwadare, K.

AUSTRALIA.

NEW SOUTH WALES.

Sydney.

Fischer, Gustave J., Public Works Dep't.
Fitzmaurice, Jas. S., 210 George St.
Jones, A. W., care of H. H. Kingsbury.
Spruson, Wilford J., 169 King St.
4

EUROPE.

AUSTRIA.

Vienna.

Egger, E., X. Simmeringstr, 187
Sahulka, Dr J. Technische Hochschule.
2

GREAT BRITAIN.

ENGLAND.

Bolton-le-Moors.—Jackson, Henry

Bristol.

Eley, Harris H., 88 Colston St.

Chester.—Keith, N. S.

Croydon.—Lewis, H. F. W.

Kingston-on-Thames.

Richardson, A E.

London.

Dawson, P , 39 Victoria St.
Forbes Geo., 34 Great George St.
Inrig, A. G., 44 White Post Lane.
Lawson. A. J., 49 Queen Victoria St.
Lorrain, James Grieve,
Norfolk House, Norfolk St., W. C.
Merz, C. H., 38 Parliament St.
Mordey, Wm. M.,
Redholm, Loughborough.
Parry, Evan, 52 Glengarry Road.
Parshall, H. F., 38 Parliament St.
Preece, Wm. H., General Post Office.
Salomons, *Sir* D. L., 49 Grosvenor St.
Winslow, I. E., 35 Parliament St.
Wharton, Chas. J., 82 Bond St.
13

Newcastle-on-Tyne.—Dobbie, R.S.

Taunton.—Haynes, F. T. J.

SCOTLAND.

Glasgow.—Kelvin, *Lord*

WALES.

Cardiff.—Walker, Sydney F

BELGIUM.

Antwerp.

Dewar, J. T., 33 Rue Bouewijns.

FRANCE.

Creusot.—Stahl, Th.

Paris.

Albanese, G. Sacco, 27 Rue de Londres.
LeBlanc, Chas., 24 Boul. des Capucines.
Mann, F. P., 17 Rue Didot.
Mix, Edgar W., 27 Rue de Londres.
Thurnauer, Ernst, 27 Rue de Londres.
Welles, F. R., 46 Ave. de Breteuil.
6

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GERMANY.

Berlin.

Bates, F. C.,
Union Elektricitats Gesellschaft.
Flesch, Chas., 22 Schiffbauerdamm.
Hessenbruch, G. S., Student at College.
Magee, Louis J., Corneliusstr 1., W.
Otten, Dr. J. D., Kufürstenstrasse, 97 III W.
Potter, H. N., Steglitzer Str. 10 Parterre
Rathenau, E., 22 Schiffbauerbamm.
West, Julius H., Handjery Str., 58, Friedenau near Berlin. 8

Munchen.—Voit, Dr. Ernst

Nuremberg.—Tischendoerfer, F. W.

ITALY.

Ivrea.—Olivetti, Camillo.

Turin.—Capuccio, M.

NETHERLANDS.

Amsterdam.—Hubrecht, Dr. H. F. R.

Delft.—Doijer, H.

RUSSIA.

St. Petersburg

Sventorzetzky, Capt. L., Military Engineering Academy.

SWEDEN.

Stockholm.—Danielson, Ernest.

Addresses Unknown.

Babcock, C. D.
Barth Bartoshevitch
Holcomb. E. R.
Mustin, H. S.
Spicer, C. W.
Varley, T. W.
Walter, Henry E. 7

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